PERMEABILITY OF POLYMERIC MATERIALS TO CONDENSABLE GASES AND ORGANIC LIQUIDS

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ABSTRACT

The permeation of seven hazardous chemicals through 12 different protective clothing materials was measured using the ASTM one-inch and two-inch cells, and the results were compared. A total of 31 material/chemical combinations were tested. The permeation of N. Hexane, Hydrazine and Toluene through Butyl Nomex, and Neoprene(Edmont) were investigated, both at room temperatrue and at 45°C. All the other permeation tests were performed only at room temperature. Nine material/chemical systems showed no permeation. For all the systems which showed permeation, the breakthrough time, steady-state permeation rate, normalized breakthrough time, and diffusion coefficient were determined.

As it was expected, the effect of the temperature was to increase the permeation rate and diffusion coefficient, and to decrease the breakthrough time. A comparison between the results of permeation tests in the one-inch and two-inch cells showed that for all the systems, the breakthrough times were almost the same in both cells. The steady-state permation rates, on the other hand, were not the same for all the systems. Five material/chemical systems showed the same rate of permeation in each cell, the other systems studied gave different permeation rates in the two cells.

Introduction

Workers involved in the production, use, and transportation of hazardous chemicals can be exposed to numerous compounds capable of causing harm upon contact with the human body. The deleterious effects of these chemicals can range from acute trauma, such as skin irritation and burns to chronic degenerative diseases, such as cancer. Since engineering controls may not eliminate all possible exposure, attention should be given to reducing the potential for direct skin contact through the use of protective clothing that resists permeation, penetration, and degradation.

In order to evaluate dermal exposure to potentially hazardous chemicals, permeation measurements are made. Two important parameters are obtained: (1) breakthrough time and (2) steady-state permeation rate. Breakthrough time serves as an estimation of the protection provided by protective clothing. The steady-state permeation rate permits quantitation of the amount of hazardous chemical to which the skin is exposed through clothing. The permeation rate, however, is dependent upon the challenge concentration, thickness of glove material, or the area exposed. It is advantageous to use coefficient of diffusion instead of permeation rate. Diffusion coefficient values allow judgements to be made about the permeability of a glove material regardless of the challenge concentration, thickness of glove material, or the area exposed. The American Society for Testing and Materials (ASTM) has adopted a chemical permeation standard test method.[2] This standard method uses a commercially available test cell.[3] The ASTM cells comes in two different sizes, one-inch cells and two-inch cells. In this study, the performance of these two ASTM cells are investigated to see if they are equivalent. The list of the systems studied is shown in Table I.

TABLE I

Systems of Protective Clothing - Chemical Tested

No.	Material-Chemical	Temperature	1-inch Cell	Two-inch Cell
1	Butyl Nomex - N. Hexane	25 °C,45 °C	Yes	Yes
2	Butyl Nomex - Toluene	25 °C,45 °C	Yes	Yes
3	Butyl Nomex - Hydrazine	25 °C,45 °C	Yes	Yes
4	Butyl Nomex - Dimethyl Formamide	25 °C,45 °C	Yes	Yes
5	Neoprene(Edmont) N. Hexane	25 °C,45 °C	Yes	Yes
6	Neoprene(Edmont) Toluene	25 °C,45 °C	Yes	Yes
7	Neoprene(Edmont) Hydrazine	25 °C,45 °C	Yes	Yes
8	PVA(Edmont) - N. Hexane	25 °C,45 °C	Yes	Yes
9	PVA(Edmont) - Toluene	25 °C,45 °C	Yes	Yes
10	PVA(Edmont) - Hydrazine	25 °C,45 °C	Yes	Yes
11	Pylox(Pioneer) - 1,1,1 Trichloethane	25 °C	No	Yes
12	Pylox(Pioneer) - Perchloroethylene	25 °C	No	Yes
13	NBR Solvex(Ansell) 1,1,1 Trichloroethane	25 °C	Yes	Yes
14	NBR Solvex(Ansell) Mehtylene Chloride	25 °C	No	Yes
15	NBR Solvex(Ansell) Perchloroethylene	25 °C	Yes	No
16	NBR(Best)- Methylene Chloride	25 °C	Yes	No
17	NBR(Best)- Perchlorothylene	25 °C	Yes	No
18	NBR Solvex(Best) 1,1,1 Trichloroethane	25 °C	No	Yes
19	Neoprene(Ansell) Methylene Chloride	25 °C	No	Yes
20	Neoprene(Ansell) Perchloroethylene	25 °C	Yes	Yes
21	Neoprene(Ansell) 1,1,1 Trichloroethane	25 °C	Yes	Yes
22	PVC #3-318(Edmont)			

Table I continued

	Methylene Chloride	25 °C	Yes	Yes
23	PVC #3-318(Edmont) Perchloroethylene	25 °C	Yes	Yes
24	Comb.#E-194(Pioneer) Methylene Chloride	25 °C	Yes	Yes
25	Comb.#E-194(Pioneer) Perchloroethylene	25 °C	Yes	Yes
26	PVC #814(Best)- Perchloroethylene	25 °C	Yes	No
27	PVC #814(Best)- Methylene Chloride	25 °C	Yes	No
28	PVC #501(Best)- Perchloroethylene	25 °C	Yes	No
29	PVC #501(Best)- Methylene Chloride	25 °C	Yes	No

Protective Clothing Materials

The protective clothing materials, manufacturers, and nominal thicknesses are shown in Table II. Samples were cut from the palm of a glove, except the butyl nomex samples which were cut from a sheet of the material. Edmont neoprene, and Edmont PVA were purchased directly from the supplier. All the other materials were provided by NASA. Only one glove of each material (items 4 through 12 in Table II) were sent to us, therefore, it was not possible to test all the materials in the two-inch as well as the one-inch cells. Another problem with the gloves was the confusion over their names. The names listed in Table II are the ones provided by NASA. Later on, the manufacturers of these gloves were contacted to check these names. It was found out that the Best Company does not manufacture any NBR gloves (item 6 and 7 in Table II). Item 7, (Best NBR) should be Best Nitrile. Ansell Company does not manufacture NBR Solvex. Solvex is the trade name for the NBR manufactured by Edmont. Therefore, item no. 5 in Table II should be Edmont NBR Solvex.

THE NAMES SUPPLIED BY NASA WERE USED THROUGHOUT THIS REPORT

Hazardous Chemicals

The hazardous chemicals used in the experiments and their manufacturers are shown in Table III. All the chemicals were used without additional purification.

TABLE II

Protective Clothing Materials Tested

No.	Material	Average Thickness (mil)	Supplier
1	Butyl Nomex	21	NASA
2	Neoprene #29-870	18	Edmont
3	Polyvinyl Alcohol #15-554	66	Edmont
4	Pylox	22	Pioneer
5	NBR Solvex	21	~~Ansell~~ Edmont
6	NBR Solvex	22	~~Best~~ Edmont
7	NBR	50	Best
8	Neoprene	22	Ansell
9	PVC, #3-318	74	Edmont
10	PVC, #814	71	Best
11	PVC, #501	74	Best
12	Combination, #E-194	21	Pioneer

TABLE III

Hazardous Chemicals Used

No.	Chemical	Supplier
1	N. Hexane	Fisher Scientific
2	Toluene	Fisher Scientific
3	Hydrazine	Fisher Scientific
4	Dimethyl Formamide	Fisher Scientific
5	1,1,1 Trichloro-ethylene	Fisher Scientific
6	Perchloroethylene	Fisher Scientific
7	Methylene Chloride	Fisher Scientific

APPARATUS

1. Ames Thickness Guage

To measure the thickness of materials to the nearest 0.001 in as specified in ASTM F739-81

2. Analytical Balance

To determine the weight per unit area of the test specimen to the nearest 0.5 mg.

3. Test Cell

The test apparatus consists of a two-chambered cell for contacting the specimen with a hazardous liquid on the specimen's normal outside surface and with a collecting medium on the specimen's normal inside surface.

The two-inch cell, as shown in Fig. A is constructed of two sections to a 51 mm (2.0 in) diameter. The section that is designed to contain the hazardous liquid chemical is 22 mm in length. The second section, which is designed to contain the collecting medium is 35 mm. The volume of challenge chamber is 45 ml, and the volume of collecting medium chamber is 100 ml.

The one-inch cell is constructed of two sections of straight pipe, each nominally sized to 25 mm (1.0 in) diameter. The section that is designed to contain the hazardous chemical is 22 mm in length and has a volume of 15 ml. The collecting medium chamber is 27 mm in length and has a volume of 15 ml.

4. Gas Chromatograph

Analysis was obtained using a Perkin-Elmer sigma 3B gas chromatograph with apezion column. Helium was used as the

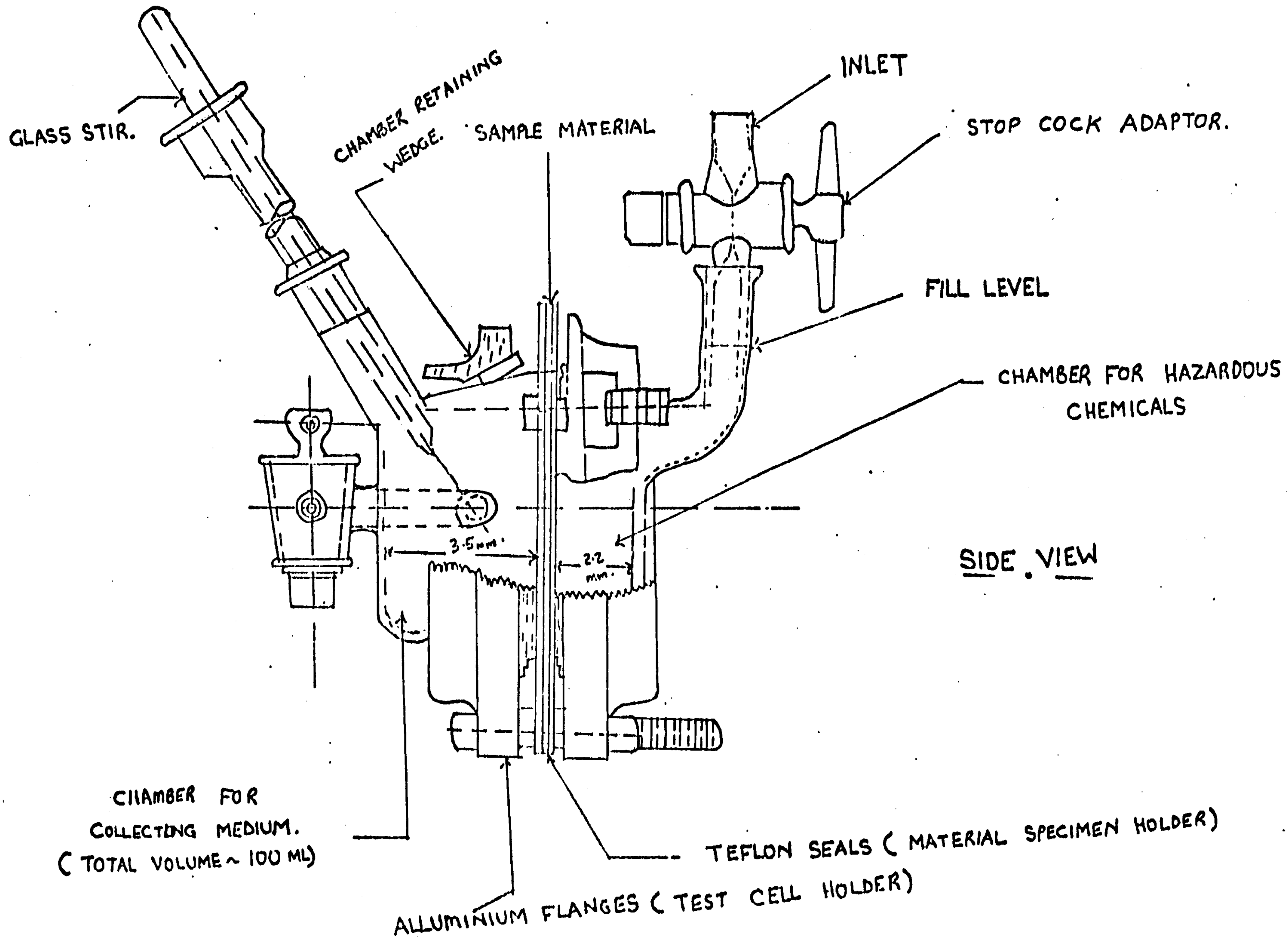
GLASS STIR.
CHAMBER RETAINING WEDGE.
SAMPLE MATERIAL
INLET
STOP COCK ADAPTOR.
FILL LEVEL
CHAMBER FOR HAZARDOUS CHEMICALS
3.5mm.
2.2 mm.
SIDE . VIEW
CHAMBER FOR COLLECTING MEDIUM. (TOTAL VOLUME ~ 100 ML)
TEFLON SEALS (MATERIAL SPECIMEN HOLDER)
ALLUMINIUM FLANGES (TEST CELL HOLDER)

FIG. A

carrier gas with a column flow rate of 30 ml/minute. Column temperature was 150^{0}C. The gas chromatograph was equipped with a minigrator for accurate area measurement. The sensitivity of the gas chromatograph was 0.3 μg/ml. The experimental set-up is shown in Fig. B.

EXPERIMENTAL

A two-inch and a one-inch ASTM permeation cell (Peace Laboratories) were used to perform the permeation experiments. Nitrogen was used as collection media. (except for hydrazine). To conduct the experiments, a square section was cut from the material, and its thickness was measured accurately with an Ames thickness gauge (measurements to the nearest 0.001 in.). After conditioning the sample for 24 hours, it was clamped in the middle of the cell, and the bolts holding the two chambers together were tightened to a torque of 30 in-lb using a torque wrench. The cell was then placed in a constant temperature bath. The experiment was performed at different nitrogen flow rates. It was found out that the best nitrogen flow rate through the one-inch and two-inch cells were 500 ml/min, and 1000 ml/min respectively. After charging the hazardous chemical, discrete samples (0.5 ml) were taken from the receiving cell and were analysed by gas chromatograph.

Butyl Nomex, Neoprene (Edmont) and PVA were tested at 25^{0}C and 45^{0}C. All the other materials were tested only at 25^{0}C. When hydrazine was used as the hazardous chemical, the collecting media was propanol (in a closed loop system).

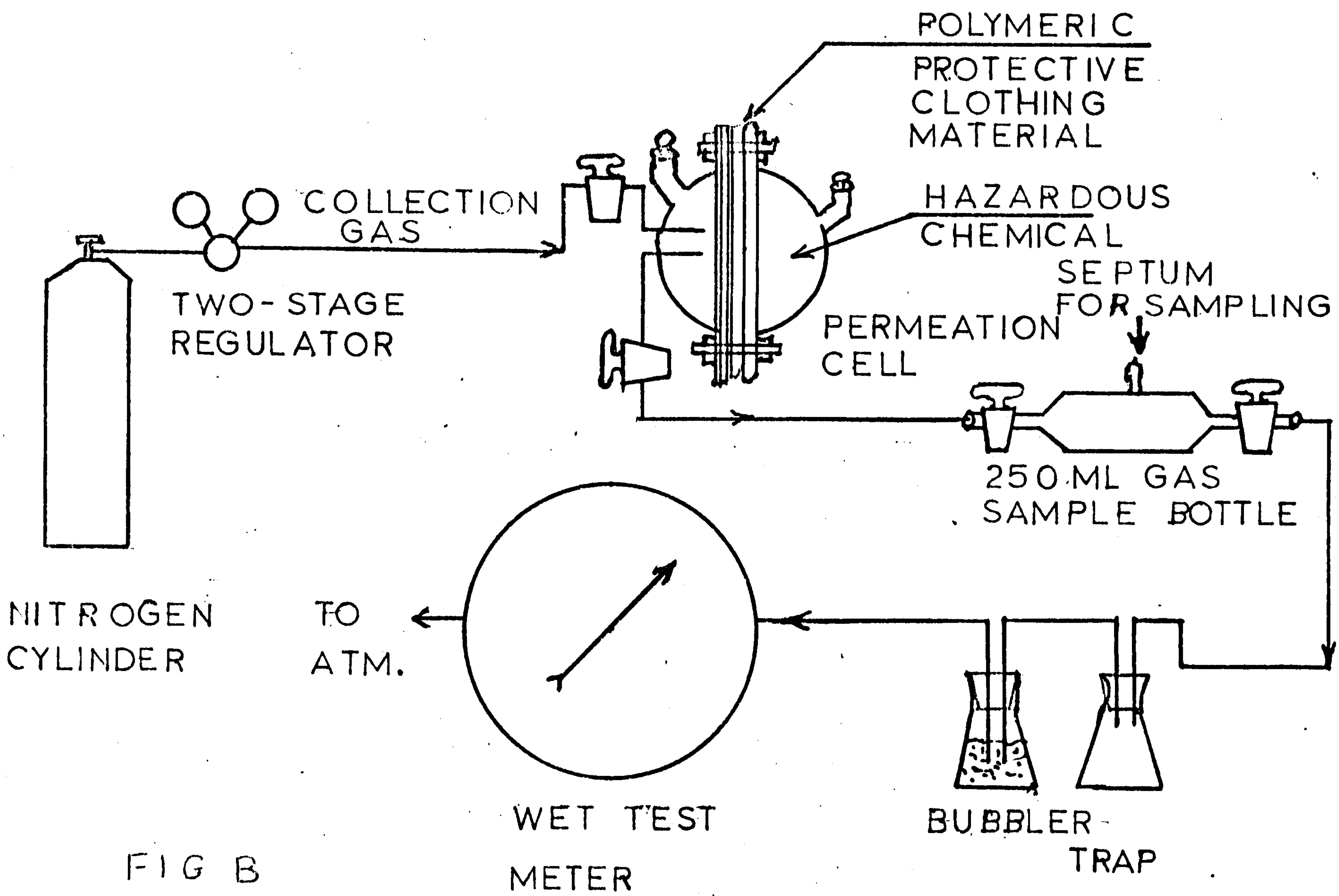
POLYMERIC
PROTECTIVE
CLOTHING
MATERIAL
HAZARDOUS
CHEMICAL
COLLECTION
GAS
TWO-STAGE
REGULATOR
SEPTUM
FOR SAMPLING
PERMEATION
CELL
250 ML GAS
SAMPLE BOTTLE
NITROGEN
CYLINDER
TO
ATM.
WET TEST
METER
BUBBLER
TRAP

FIG B

Breakthrough times were normalized to eliminate the statistical difference which is due solely to varying material thickness. Since breakthrough times are directly proportional to the square of the material thickness, normalized breakthrough times were calculated as follows:[1,4,5]

$$T = \frac{T_B}{L^2} \qquad (1)$$

Where T is breakthrough time, minutes, L is thickness of material, mil, and T is normalized breakthrough time (min/mil).

For an open flow system, the steady-state permeation rate is given by:

$$J = \frac{F\,C_s}{A} \qquad (2)$$

Where F is flow rate of collection medium (nitrogen) ml/min. C_s is steady-state concentration of hazardous chemical in the collection medium, μg/ml. J is the steady-state permeation rate μg/cm^2-min.

In addition to permeation rate, the steady-state coefficient of diffusion was also determined from the following equation:

$$J = D\,\frac{C_1 - C_2}{t} \qquad (3)$$

Where D_s is steady-state diffusion coefficient, cm^2/min. C_1 is permeant concentration in the upstream (higher concentration) surface of the membrane. C_2 is the permeant concentration in the downstream surface of the membrane. C_2 is considered to be zero when permeation tests are carried out such that downstream membrane surface is continuously exposed to and washed by fluid (collection medium) in which the concentration of the permeant is far below saturation. C_1 is equal to the solubility of the compound in the polymer; and was determined by a separate, long term immersion experiment. Samples of protective garment materials were immersed in the chemicals at 25 ^{0}C and 45 ^{0}C for several hours. By weighing the material before and after the immersion, it was possible to determine the solubility of chemicals in the materials.

RESULTS

Twelve(12) protective clothing materials were tested against seven hazardous chemicals. A total of 35 protective clothing-chemical systems were studied, and the results were reported in the monthly reports. For each system, several runs were made. Three of the protective clothing materials, namely, Butyl-nomex, Neoprene (Edmont), and PVA (Edmont), were tested at room temperature as well as at 45^{0}C. All the other materials were tested only at room temperature. The permeation curve for some of the runs of each system are shown in Figures 1 through 31. Table IV shows average breakthrough times, and steady-state permation rates for all the systems investigated in one-inch and/or two-inch cells. Some of the materials were tested only in one of the cells (one-inch or two-inch). This is due to the fact

TABLE IV

Permeation of Hazardous Chemicals Through Protective Clothing Materials

No.	Material-Chemical	Temperature °C	One Inch-Cell: Breakthrough Time Min.	One Inch-Cell: Steady-State Permeation Rate µg/cm -min	Two Inch-Cell: Breakthrough Time Min.	Two Inch-Cell: Steady-State Permeation Rate µg/cm -min
1	Butyl Nomex - N. Hexane	25	17	144	18	145
2	Butyl Nomex - N. Hexane	45	12	190	10	227
3	Butyl Nomex - Toluene	25	31	95	25	95
4	Butyl Nomex - Toluene	45	18	218	13	165
5	Butyl Nomex - Hydrazine	25,45	No Permeation		No Permeation	
6	Butyl Nomex - Dimethyl Formamide	25,45	No Permeation		No Permeation	
7	Neoprene (Edmont) - N. Hexane	25	No Permeation		No Permeation	
8	Neoprene (Edmont) - N. Hexane	45	No Permeation		No Permeation	
9	Neoprene (Edmont) - Toluene	25	11	1600	10	1600
10	Neoprene (Edmont) - Toluene	45	6	2800	6	2400
11	Neoprene (Edmont) - Hydrazine	25	No Permeation		No Permeation	
12	PVA (Edmont) - N. Hexane	25	No Permeation		No Permeation	
13	PVA (Edmont) - N. Hexane	45	No Permeation		No Permeation	
14	PVA (Edmont) - Toluene	25	No Permeation		No Permeation	
15	PVA (Edmont) - Toluene	45	No Permeation		No Permeation	
16	PVA (Edmont) - Hydrazine	25	No Permeation		No Permeation	
17	Pylox(Pioneer) - 1,1,1 Trichloroethane	25			10-22	200
18	Pylox(Pioneer) - Perchloroethylene	25			16	350
19	NBR Solvex(Ansell) - Methylene Chloride	25			38	450
20	NBR Solves(Ansell) - Perchloroethylene	25	5		3	4500

TABLE IV continued

21	NBR Solvex (Ansell) - Methylene Chloride	25	No Permeation			
22	NBR (Best) - Methylene Chloride	25	5	1450	2	4500
23	NBR (Best) - Perchloro-ethylene	25	No Permeation			
24	NBR Solvex (Best) - 1,1,1 Trichloroethane	25	57	430		
25	Neoprene (Ansell) - Per-chloroethylene	25	6	2800	10	1800
26	Neoprene (Ansell) - Methylene Chloride	25			1	3250
27	Neoprene (Ansell) - 1,1,1 Trichloroethane	25	15	1100	9	940
28	PVC #3-318 (Edmont) - Methylene Chloride	25	12	1450	9	1300
29	PVC #3-318 (Edmont) - Perchloroethylene	25	78	180	57	180
30	Comb. #E-194 (Pioneer) - Methylene Chloride	25	2	4200	2	2550
31	Comb. #E-194 (Pioneer) - Perchloroethylene	25	5	3600	5	1900
32	PVC #814 (Best) - Perchloro-ethylene	25	37	350		
33	PVC #814 (Best) - Methylene Chloride	25	9	1500		
34	PVC #501 (Best) - Perchloro-ethylene	25	73	290		
35	PVC #501 (Best) - Methylene Chloride	25	11	1300		

that not enough material was available to do the permeation experiment in both cells.

The solubility of hazardous chemicals in the polymers were found from immersion experiments, and they are given in Table V.

The breakthrough times were normalized according to equation (1), and the steady-state diffusion coefficients were calculated from equation(3). The results are shown in Table VI.

DISCUSSION

Out of the 35 systems investigated, 12 showed no permeation (see Table IV). Nine systems were studied using only one of the cells, and 14 systems were tested in both one-inch and two-inch cells. Therefore, the permeation data for 14 systems are used to evaluate ASTM one-inch and two-inch cells. The results are shown in Table VII.

The breakthrough times for the one-inch and two-inch cells are very close. System 7 (NBR Solvex - 1,1,1 Trichloroethane) shows breakthrough times of 56 and 36 minutes for the one-inch and two-inch cell respectively. This is because the thickness of the materials used are different (25 mil for the one-inch cell and 20 mil for the two-inch cell). As Table VI shows, the normalized breakthrough times are essentially the same for this system. System 9 (Neoprene - Perchloroethylene) shows breakthrough times of 6 and 10 minutes. This is again due to the difference in the thickness of Neoprene (22 mil for one-inch cell and 25 for two-inch cell). System 12 (Edmont PVC #3-318-Perchloroethylene) gives breakthrough times of 78 and 57 minutes.

TABLE V

Solubility of Chemicals in Polymers

No.	Material-Chemical	Temparature, ^{0}C	Solubility, µg/cm
1	Butyl Nomex - N. Hexane	25	0.469
2	Butyl Nomex - N. Hexane	45	0.419
3	Butyl Nomex - Toluene	25	1.56
4	Butyl Nomex - Toluene	45	1.64
5	Butyl Nomex - Hydrazine	25	0.048
6	Butyl Nomex - Dimethyl Formamide	25	0.031
7	Neoprene(Edmont)- N. Hexane	25	0.192
8	Neoprene(Edmont)- N. Hexane	45	0.367
9	Neoprene(Edmont)- Toluene	25	2.58
10	Neoprene(Edmont)- Toluene	45	2.58
11	Neoprene(Edmont)- Hydrazine	25	0.263
12	Pylox(Pioneer)- 1,1,1, Tri-chloroethane	25	0.189
13	Pylox(Pioneer)-Perchlorethylene	25	0.04
14	NBR Solvex(Ansell)- 1,1,1 Trichloroethane	25	1.97
15	NBR Solvex(Ansell)- Methylene Chloride	25	4.71
16	NBR Solvex(Ansell)- Perchloro-ethylene	25	1.135
17	NBR (Best)- Methylene Chloride	25	1.87
18	NBR (Best)- Perchloroethylene	25	1.25
19	NBR Solvex(Best)- 1,1,1 Tri-chloroethane	25	2.16
20	Neoprene(Ansell)- Perchloroethylene	25	1.87
21	Neoprene(Ansell)- Methylene Chloride	25	2.85
22	Neoprene(Ansell)- 1,1,1 Tri-Trichloroethane	25	3.13
23	PVC #3-318(Edmont)- Methylene Chloride	25	0.563
24	PVC #3-318(Edmont)- Perchloro-ethylene	25	0.068
25	Comb. #E-194(Pioneer)- Methylene Chloride	25	3.87
26	Comb. #E-194(Pioneer)- Perchloro-ethylene	25	8.75
27	PVC #814(Best)- Perchloroethylene	25	0.034
28	PVC #814(Best)- Methylene Chloride	25	0.92
29	PVC #501(Best)- Perchloroethylene	25	0.097
30	PVC #501(Best)- Methylene Chloride	25	1.15

TABLE VI

Normalized Breakthrough Times and Diffusion Coefficients of Chemical - Polymer Systems

No.	Material - Chemical	Temperature ^0C	One-inch cell: Normilized Breakthrough Time min/(mil)^2	One-inch cell: Diffusion Coefficient cm^2/min.	Two-inch cell: Normalized Breakthrough Time min/(mil)^2	Two-inch cell: Diffusion Coefficient cm^2/min.
1	Butyl Nomex - N. Hexane	25	3.85×10^{-2}	1.64×10^{-5}	4.08×10^{-2}	1.65×10^{-5}
2	Butyl Nomex - N. Hexane	45	2.72×10^{-2}	2.42×10^{-6}	2.27×10^{-2}	2.89×10^{-6}
3	Butyl Nomex - Toluene	25	7.03×10^{-2}	3.25×10^{-6}	5.67×10^{-2}	3.25×10^{-6}
4	Butyl Nomex - Toluene	45	4.08×10^{-2}	7.09×10^{-6}	2.95×10^{-2}	5.37×10^{-6}
5	Butyl Nomex - Hydrazine	25,45	No Permeation		No Permeation	
6	Butyl Nomex - Dimethyl Formamide	25,45	No Permeation		No Permeation	
7	Neoprene(Edmont)-N. Hexane	25	No Permeation		No Permeation	
8	Neoprene(Edmont)-N. Hexane	45	No Permeation		No Permeation	
9	Neoprene(Edmont)-Toluene	25	3.39×10^{-2}	2.83×10^{-5}	3.09×10^{-2}	2.83×10^{-5}
10	Neoprene(Edmont)-Toluene	45	1.85×10^{-2}	4.96×10^{-5}	1.85×10^{-2}	4.25×10^{-5}
11	Neoprene(Edmont)-Hydrazine	25	No Permeation		No Permeation	
12	PVA (Edmont)-N. Hexane	25	No Permeation		No Permeation	
13	PVA (Edmont)-N. Hexane	45	No Permeation		No Permeation	
14	PVA (Edmont)-Toluene	25	No Permeation		No Permeation	
15	PVA (Edmont)-Toluene	45	No Permeation		No Permeation	
16	PVA (Edmont)-Hydrazine	25	No Permeation		No Permeation	
17	Pylox(Pioneer)-1,1,1 Trichloroethane	25			$3.63\text{-}4.54 \times 10^{-2}$	5.91×10^{-5}
18	Pylox(Pioneer)-Perchloroethylene	25			3.30×10^{-2}	4.89×10^{-4}
19	NBR Solvex(Ansell)- 1,1,1 Trichloroethane	25	8.16×10^{-2}	1.45×10^{-5}	8.61×10^{-2}	1.16×10^{-5}
20	NBR Solvex(Ansell)- Methylene Chloride	25			0.68×10^{-2}	5.10×10^{-5}
21	NBR Solvex(Ansell)- Perchloroethylene	25	No Permeation			
22	NBR (Best)- Methylene Chloride	25	0.2×10^{-2}	9.85×10^{-5}	0.08×10^{-2}	3.06×10^{-4}
23	NBR (Best)- Perchloroethylene	25	No Permeation			

TABLE VI continued

4	NBR Solvex (Best)- 1,1,1 Trichloroethane	25	11.78×10^{-2}	1.11×10^{-5}		
5	Neoprene(Ansell)- Perchloroethylene	25	1.24×10^{-2}	8.21×10^{-5}	2.07×10^{-2}	6.04×10^{-5}
6	Neoprene(Ansell)- Methylene Chloride	25			0.2×10^{-2}	6.37×10^{-5}
7	Neoprene(Ansell)- 1,1,1 Trichloroethane	25	3.10×10^{-2}	1.96×10^{-5}	1.86×10^{-2}	1.68×10^{-5}
8	PVC #3-318(Edmont)- Methylene Chloride	25	0.219×10^{-2}	4.84×10^{-4}	0.16×10^{-2}	4.34×10^{-4}
9	PVC #3-318(Edmont)- Perchloroethylene	25	1.05×10^{-2}	5.77×10^{-4}	1.04×10^{-2}	4.97×10^{-4}
0	Comb. #E-194(Pioneer)- Methylene Chloride	25	1.36×10^{-2}	5.79×10^{-5}	1.36×10^{-2}	3.51×10^{-5}
1	Comb. #E-194(Pioneer)- Perchloroethylene	25	3.40×10^{-2}	2.19×10^{-5}	3.40×10^{-2}	1.16×10^{-5}
2	PVC #814(Best)- Perchloroethylene	25	0.73×10^{-2}	1.86×10^{-3}		
3	PVC #814(Best)- Methylene Chloride	25	$.18 \times 10^{-2}$	2.94×10^{-4}		
4	PVC #501(Best)- Perchloroethylene	25	1.33×10^{-2}	5.62×10^{-4}		
5	PVC #501(Best)- Methylene Chloride	25	$.20 \times 10^{-2}$	2.12×10^{-4}		

Thickness data for this system reveals that the materials used for this experiment had different thickness (86 mil for one-inch cell, and 74 mil for two-inch cell). The analysis of the breakthrough times, specially the normalized breakthrough times, shows that the two cells are equivalent.

The results of the steady-state permeation rates on the other hand, are more difficult to analyse. Five systems (1,3,5,7,12) shows the same permeation rate for the one-inch and two-inch cells. Systems 2 and 8 gives higher permeation rates in the two-inch cell. All the other systems (4,6,9.10,11,13,14) shows a higher permeation rate in a one-inch cell.

TABLE VII

Comparison between one-inch and two-inch ASTM cell
Breakthrough times and Permeation rates

No.	Material- Chemical	Temperature ^{0}C	Breakthrough Time, min. one-inch cell	Breakthrough Time, min. two-inch cell	Steady-state Permeation Rate $\mu g/cm^2 min.$ one-inch cell	Steady-state Permeation Rate $\mu g/cm^2 min.$ two-inch cell
1	Butyl Nomex - N. Hexane	25	17	18	144	145
2	Butyl Nomex - N. Hexane	45	12	10	190	227
3	Butyl Nomex - Toluene	25	31	25	95	95
4	Butyl Nomex - Toluene	45	18	13	218	165
5	Neoprene(Edmont) - Toluene	25	11	10	1600	1600
6	Neoprene(Edmont) - Toluene	45	6	6	2800	2400
7	NBR Solvex (Ansell) - 1,1,1 Trichloroethane	25	56	36	450	450
8	NBR (Best) - Methylene Chloride	25	5	2	1450	4500
9	Neoprene(Ansell) - Perchloro-ethylene	25	6	10	2800	1800
10	Neoprene(Ansell) - 1,1,1 -Tri-chloroethane	25	15	9	1100	940
11	PVC #3-318(Edmont) - Methylene Chloride	25	12	9	1450	1300
12	PVC #3-318(Edmont) - Perchlo-roethylene	25	78	57	180	180
13	Comb. #E-194(Pioneer) - Perchloroethylene	25	5	5	3600	1900
14	Comb. #E-194(Pioneer) - Methy-lene Chloride	25	2	2	4200	2550

TABLE VIII

Comparison between one-inch and two-inch ASTM Cell
Normalized breakthrough times and Diffusion coefficients

No.	Material-Chemical	Temperature ^0C	Normalized breakthrough time min		Diffusion Coefficient $cm^2/min.$	
			one-inch cell	two-inch cell	one-inch cell	two-inch cell
1	Butyl Nomex - N. Hexane	25	3.85×10^{-2}	4.08×10^{-2}	1.64×10^{-5}	1.65×10^{-5}
2	Butyl Nomex - N. Hexane	45	2.72×10^{-2}	2.27×10^{-2}	2.42×10^{-6}	2.89×10^{-6}
3	Butyl Nomex - Toluene	25	7.03×10^{-2}	5.67×10^{-2}	3.25×10^{-6}	3.75×10^{-6}
4	Butyl Nomex - Toluene	45	4.08×10^{-2}	2.95×10^{-2}	7.09×10^{-6}	5.37×10^{-6}
5	Neoprene(Edmont)- Toluene	25	3.39×10^{-2}	3.09×10^{-2}	2.83×10^{-5}	2.83×10^{-5}
6	Neoprene(Edmont)- Toluene	45	1.85×10^{-2}	1.85×10^{-2}	4.96×10^{-5}	4.25×10^{-5}
7	NBR Solvex (Ansell)- 1,1,1 Trichloroethane	25	8.16×10^{-2}	8.61×10^{-2}	1.45×10^{-5}	1.16×10^{-5}
8	NBR(Best) - Methylene Chloride	25	0.2×10^{-2}	0.08×10^{-2}	9.85×10^{-5}	3.06×10^{-4}
9	Neoprene(Ansell)- Perchloroethylene	25	1.24×10^{-2}	2.07×10^{-2}	8.21×10^{-5}	6.04×10^{-5}
10	Neoprene(Ansell)- 1,1,1 Trichloro-ethane	25	3.1×10^{-2}	1.86×10^{-2}	1.96×10^{-5}	1.68×10^{-5}
11	PVC #3-318(Edmont) - Methylene Chloride	25	0.219×10^{-2}	0.16×10^{-2}	4.84×10^{-4}	4.34×10^{-4}
12	PVC #3-318(Edmont) - Perchloro-ethylene	25	1.05×10^{-2}	1.04×10^{-2}	5.77×10^{-4}	4.97×10^{-4}
13	Comb#E-194(Pioneer) - Perchloro-ethylene	25	3.4×10^{-2}	3.4×10^{-2}	2.19×10^{-5}	1.16×10^{-5}
14	Comb#E-194(Pioneer) - Methylene Chloride	25	1.36×10^{-2}	1.36×10^{-2}	5.79×10^{-5}	3.51×10^{-5}

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16. N. Vahdat, eighth progress report on "Permeabiltiy of Polymeric Materials to Condensable Gases and Organic Liquids", for the period June 19, 1985 to July 18, 1985.

17. N. Vahdat, ninth progress report on "Permeability of Polymeric Materials to Condensable Gases and Organic Liquids", for the period July 19, 1985 to August 18, 1985.

18. N. Vahdat, tenth progress report on "Permeability of Polymeric Materials to Condensable Gases and Organic Liquids", for the period August 19, 1985 to September 18, 1985.

19. N. Vahdat, eleventh progress report on "Permeability of Polymeric Materials to Condensable Gases and Organic Liquids", for the period September 19, 1985 to October 18, 1985.

20. N. Vahdat, twelveth progress report on "Permeability of Polymeric Materials to Condensable Gases and Organic Liquids", for the period October 19, 1985 to November 18, 1985.

APPENDIX

List of Permeation Curves

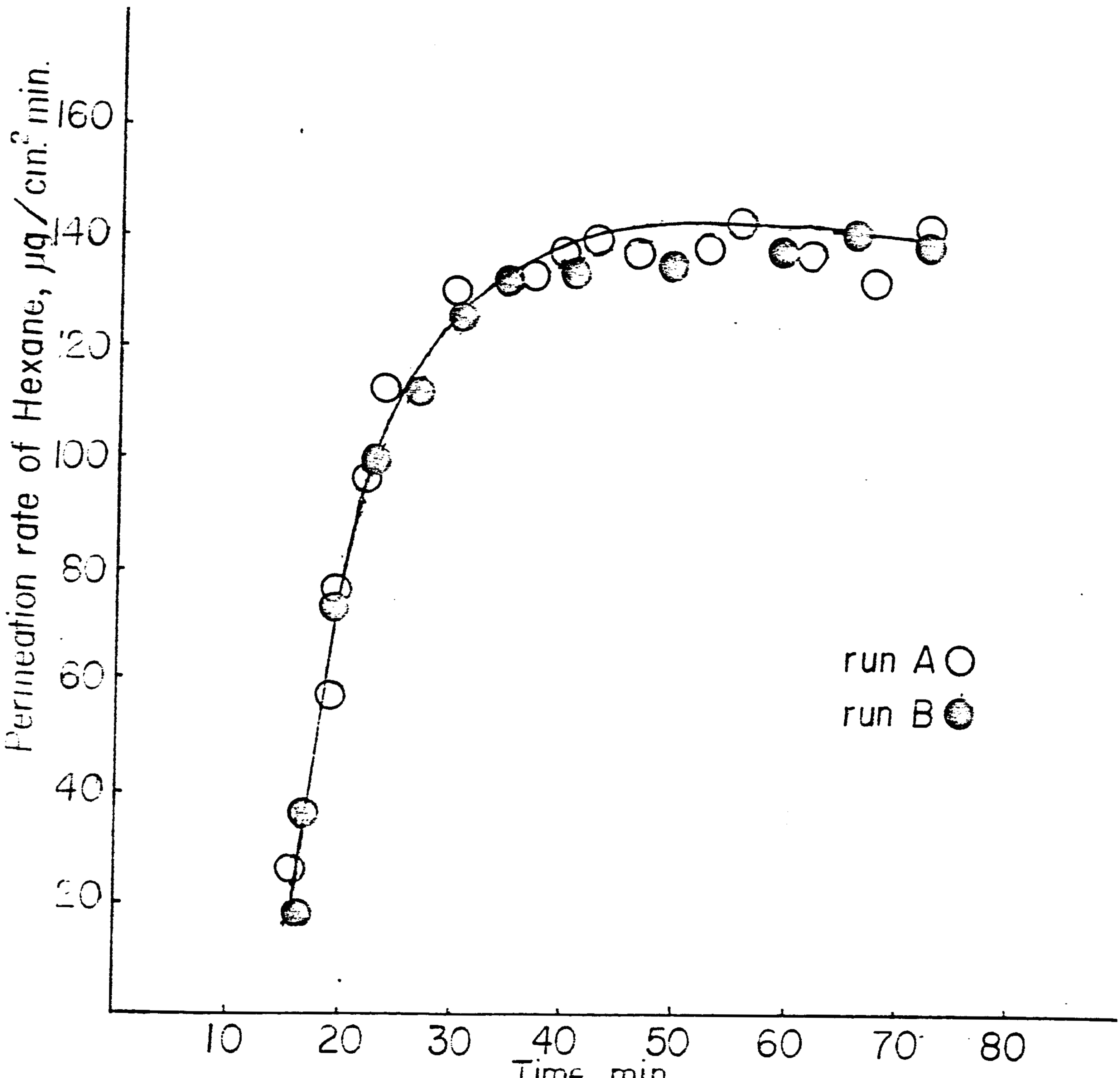

Fig. 1 Permeation of Hexane through Butyl Nomex at room temperature One-inch cell

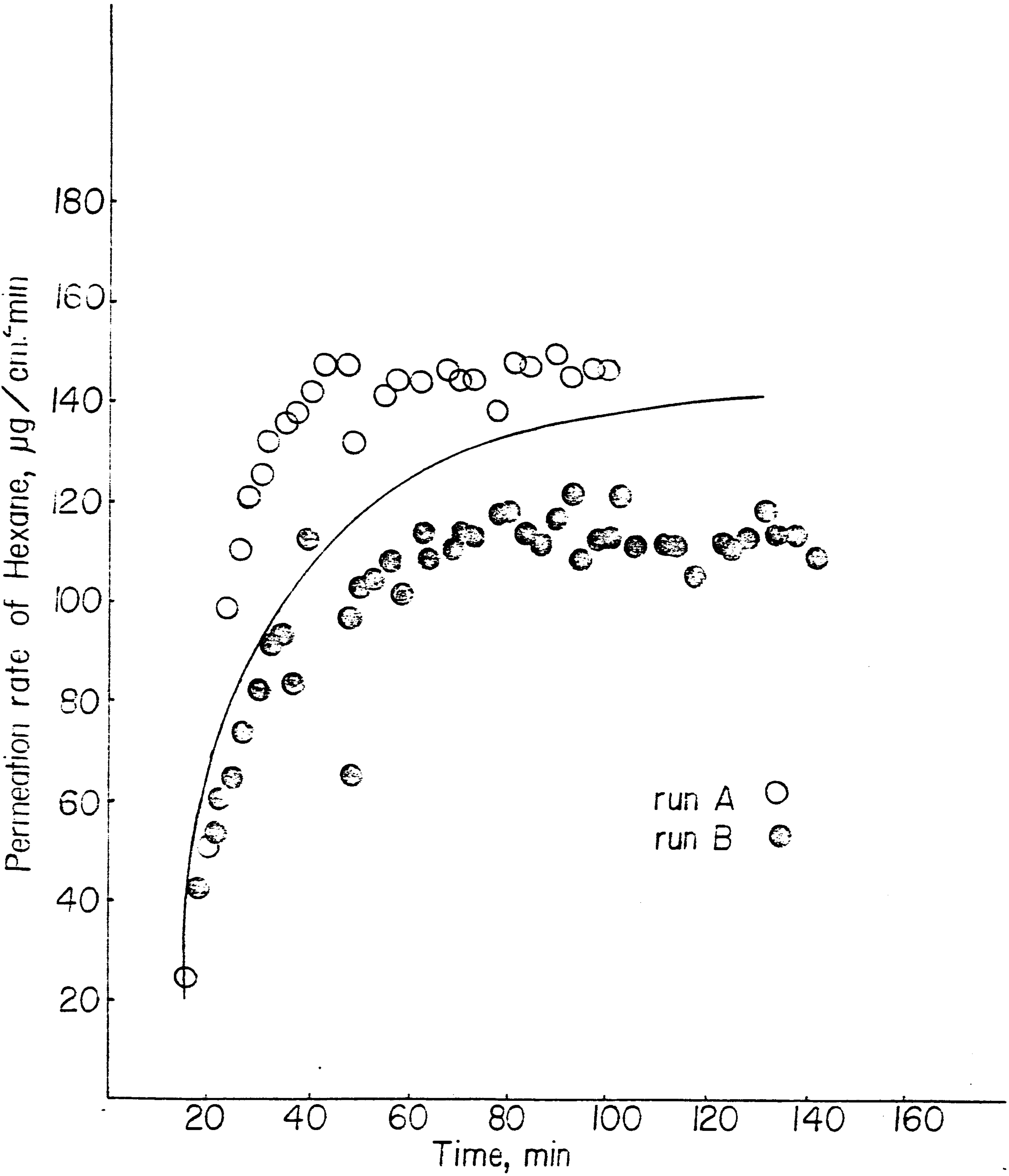

Fig. 2 Permeation of Hexane through Butyl Nomex at room temperature, Two-inch cell

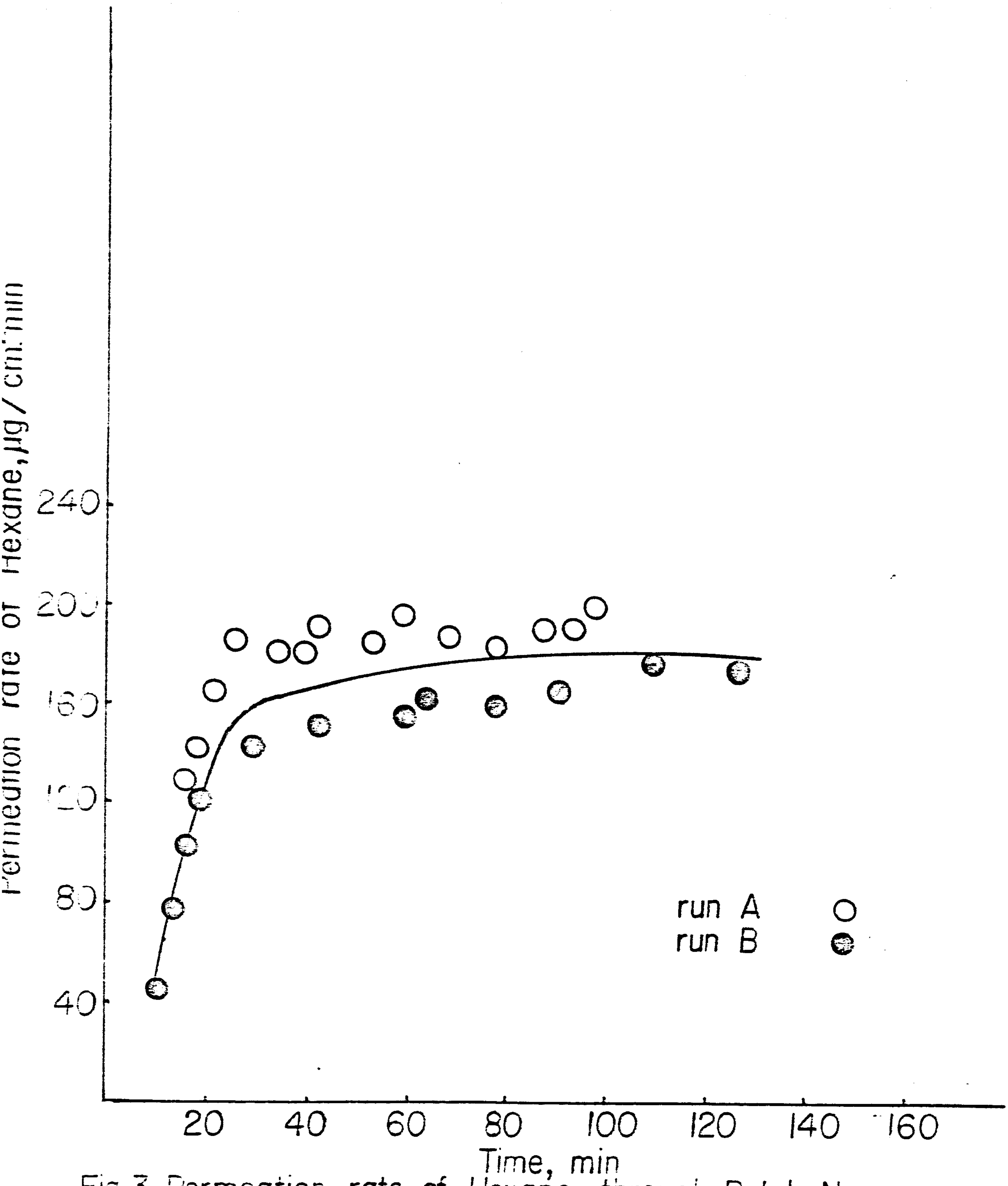

Fig. 3 Permeation rate of Hexane through Butyl Nomex at 45° C. One-inch cell

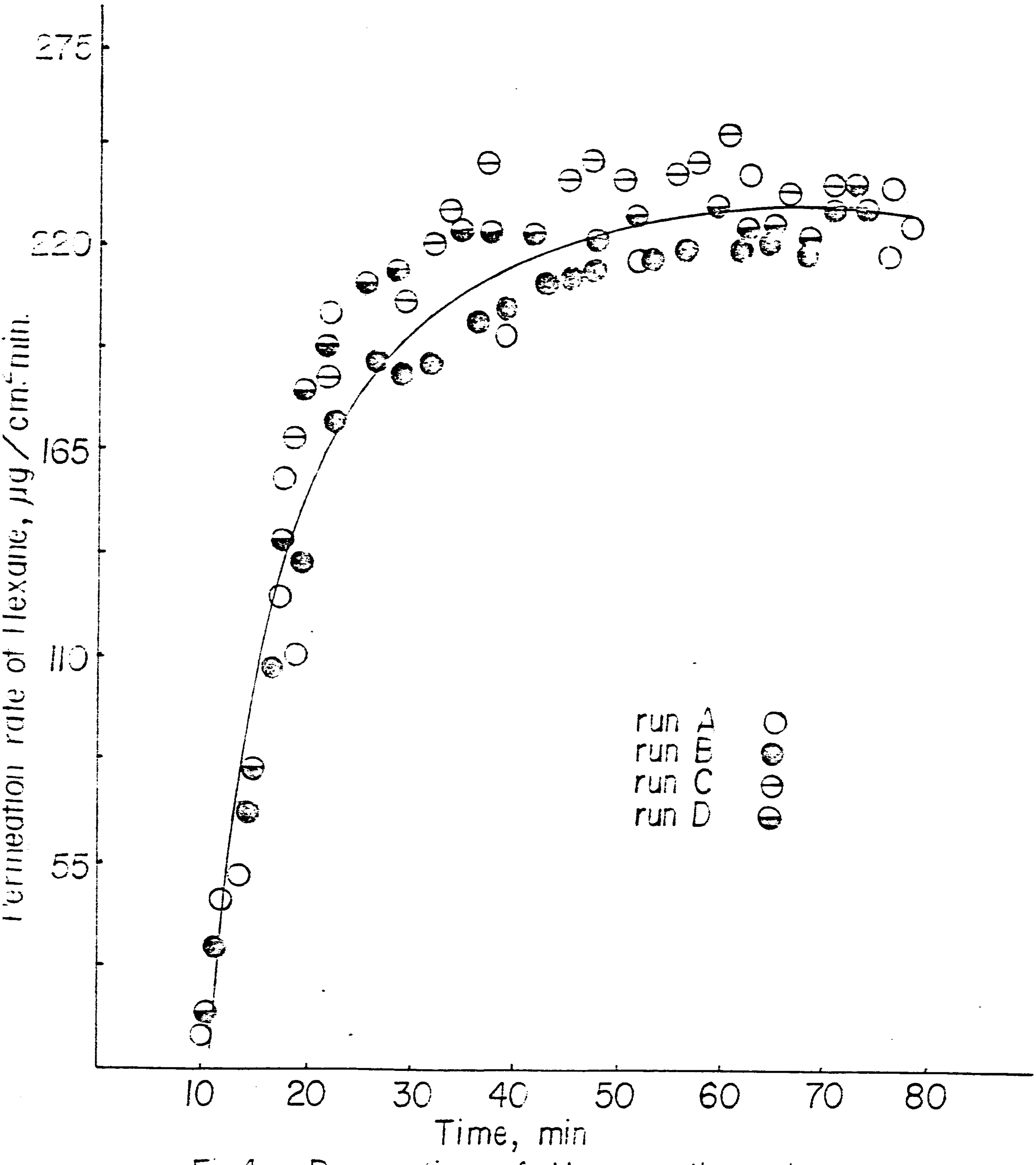

Fig.4 Permeation of Hexane through Butyl Nomex at 45°C, Two-inch cell

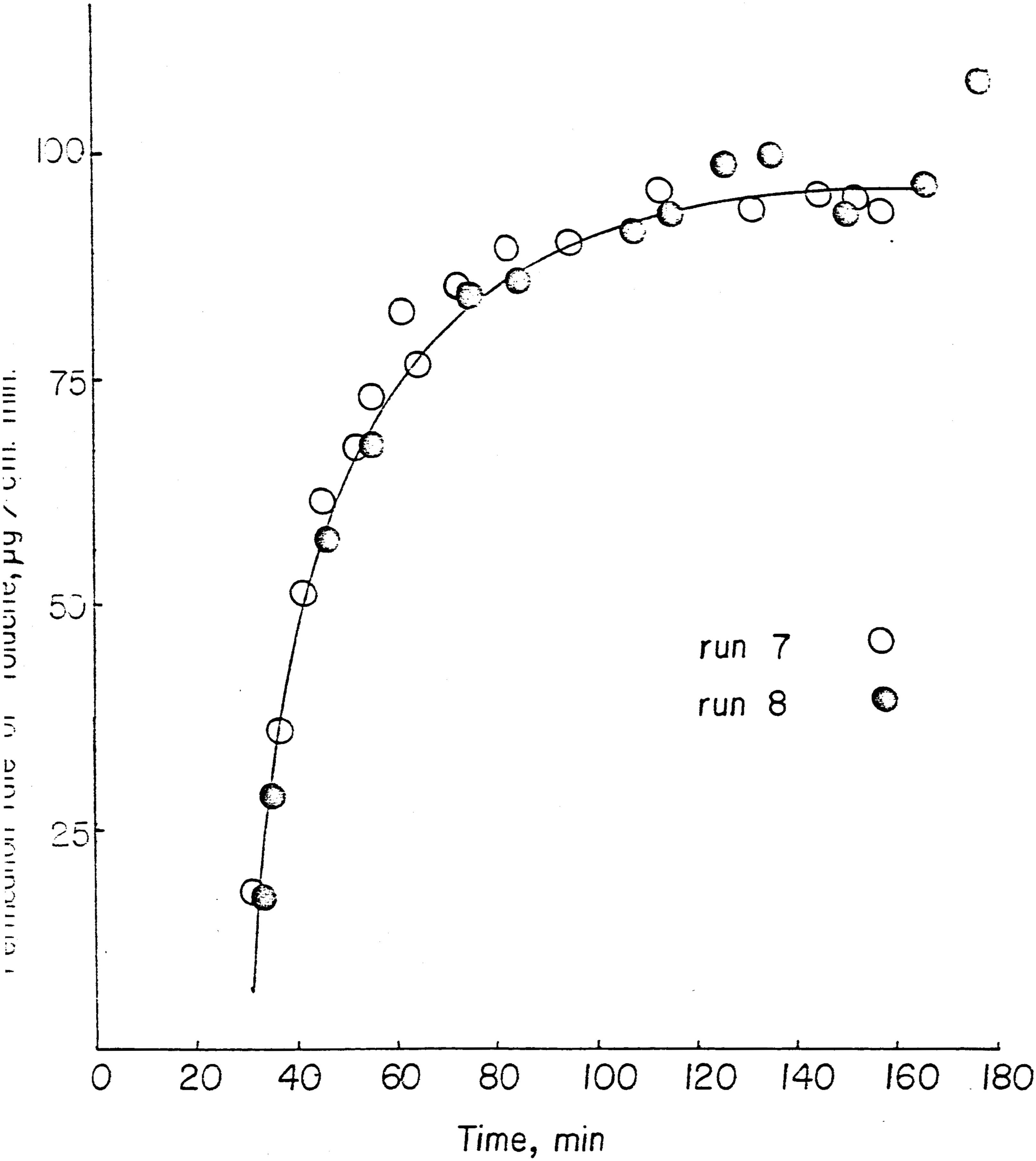

Fig 5 Permeation of Toluene through Butyl Nomex at room temperature. One-inch cell

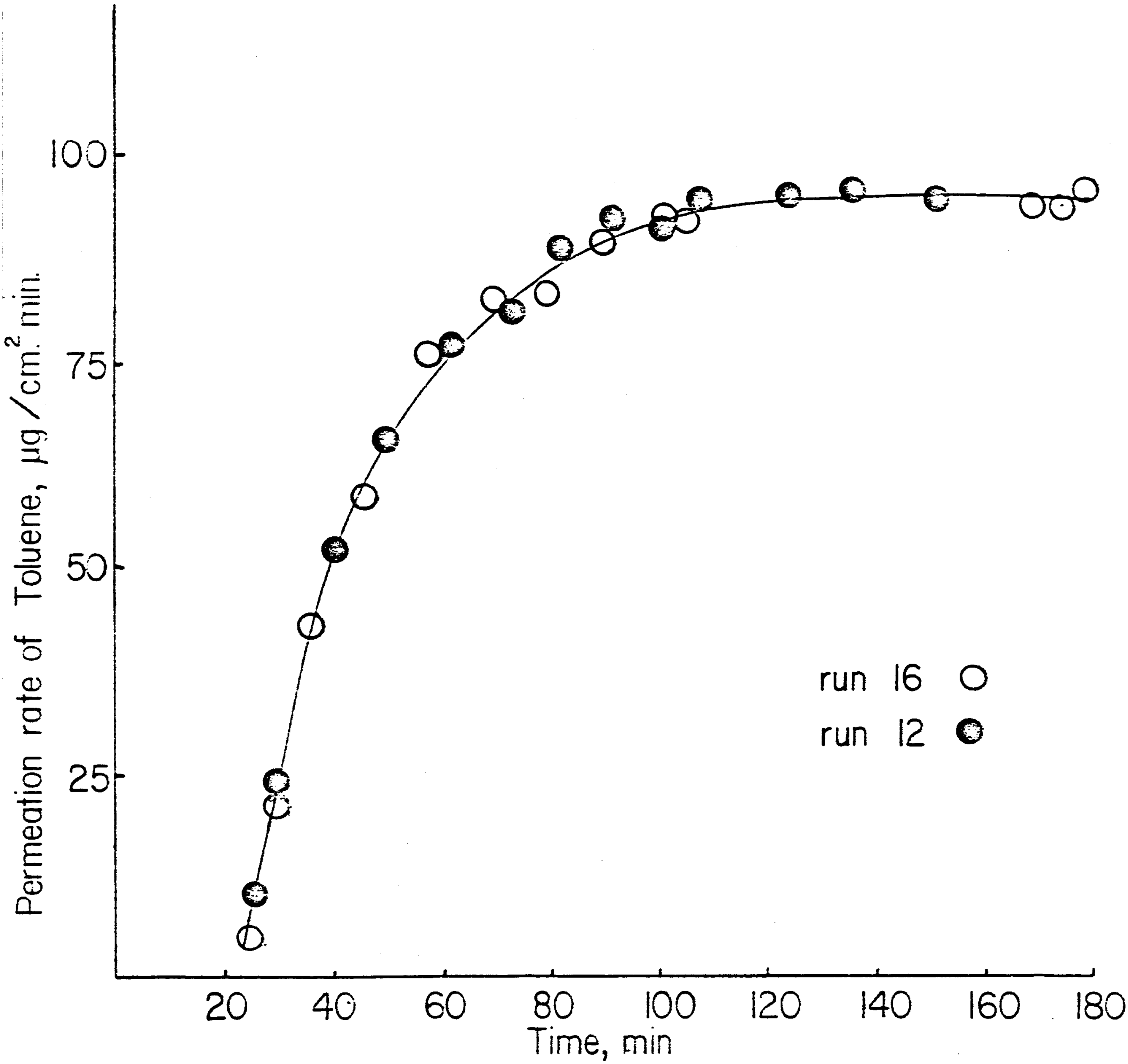

Fig. 6 Permeation of Toluene through Butyl Nomex at room temperature. Two-inch cell

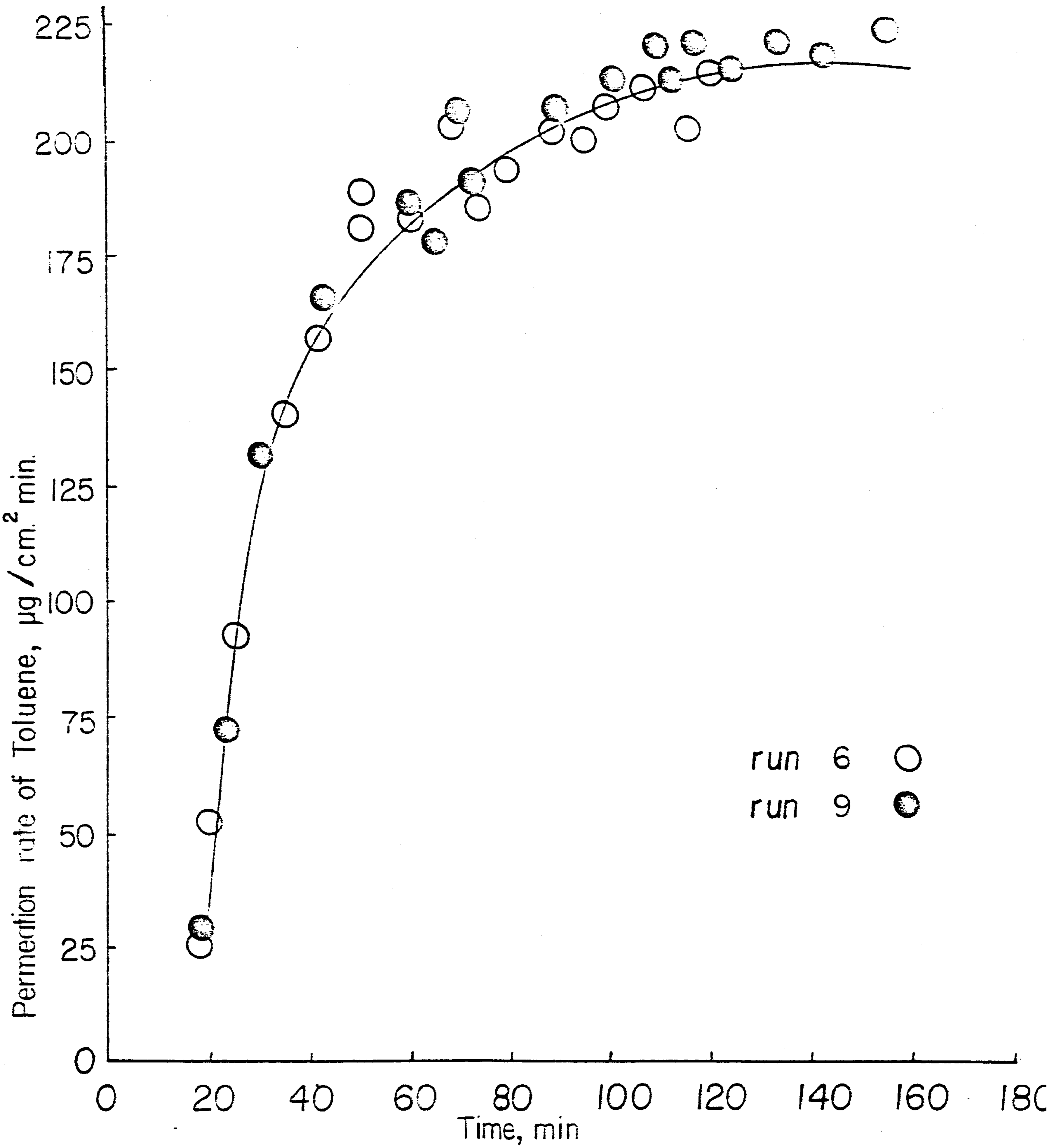

Fig. 7 Permeation of Toluene through Butyl Nomex at 45°C.
One-inch cell

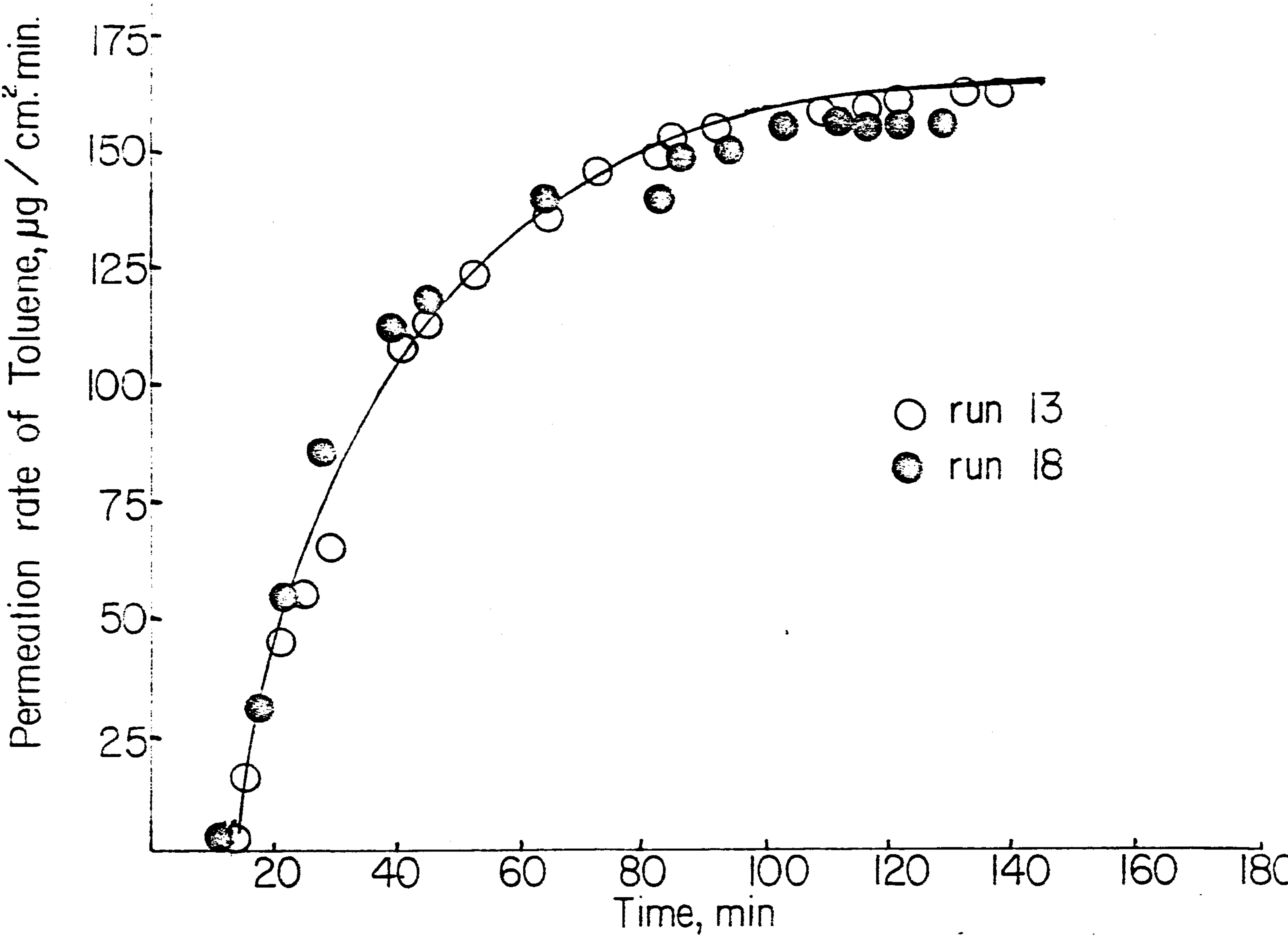

Fig. 8 Permeation rate of Toluene through Butyl Nomex at 45°C. Two-inch cell

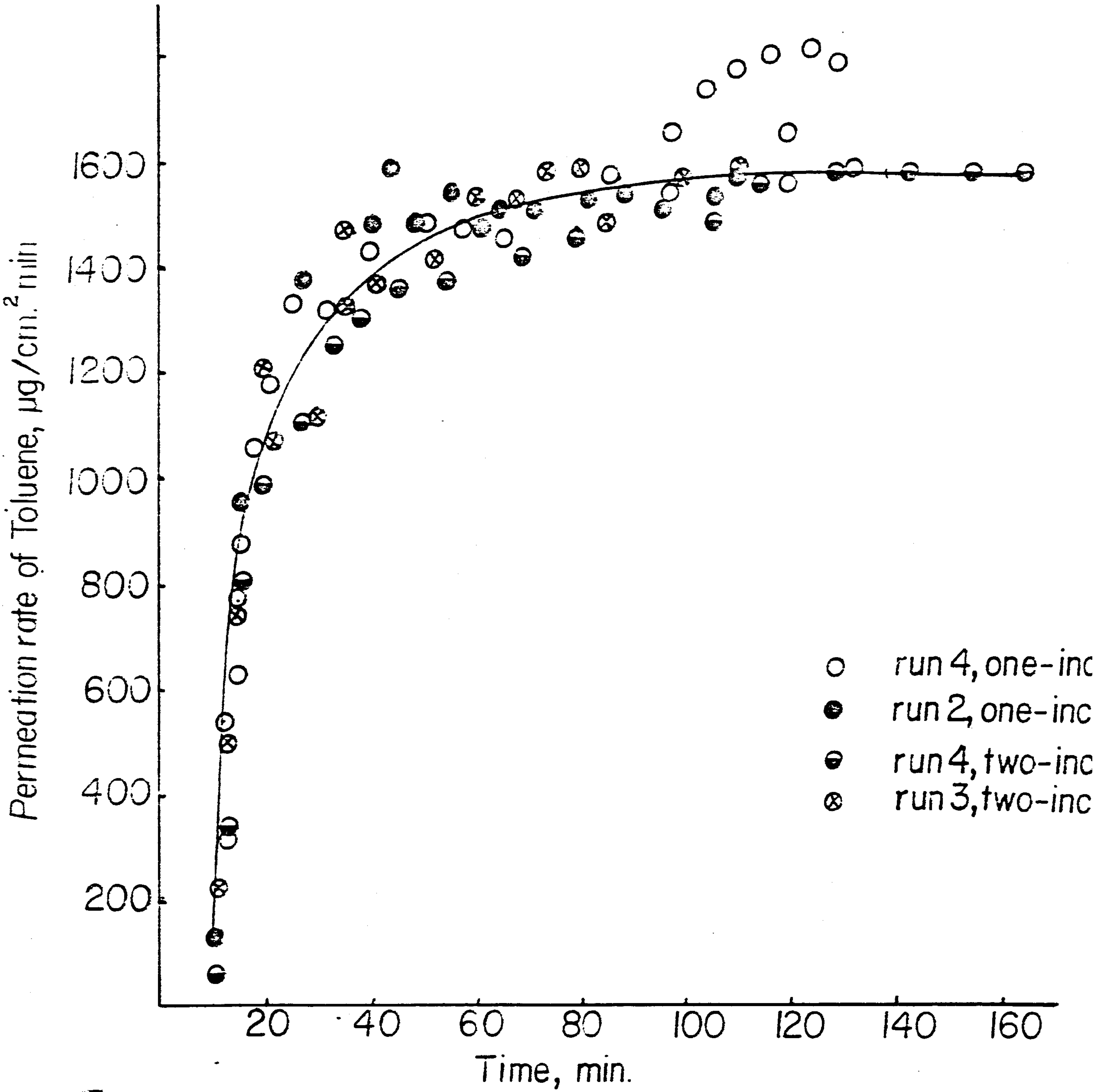

Fig. 9 Permeation of Toluene through Neoprene at room temperature

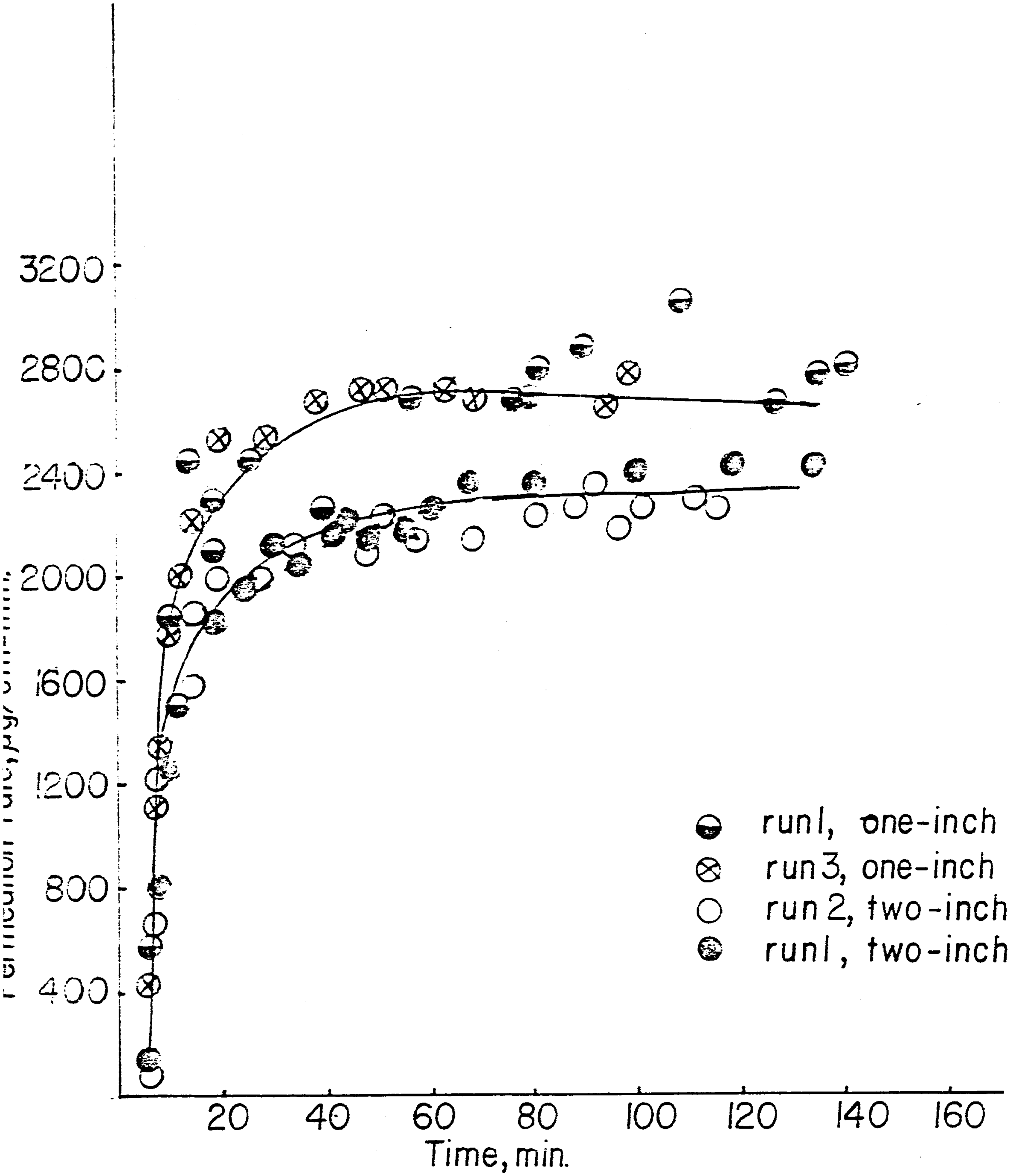

Fig. 10 Permeation of Toluene through Neoprene at 45°C

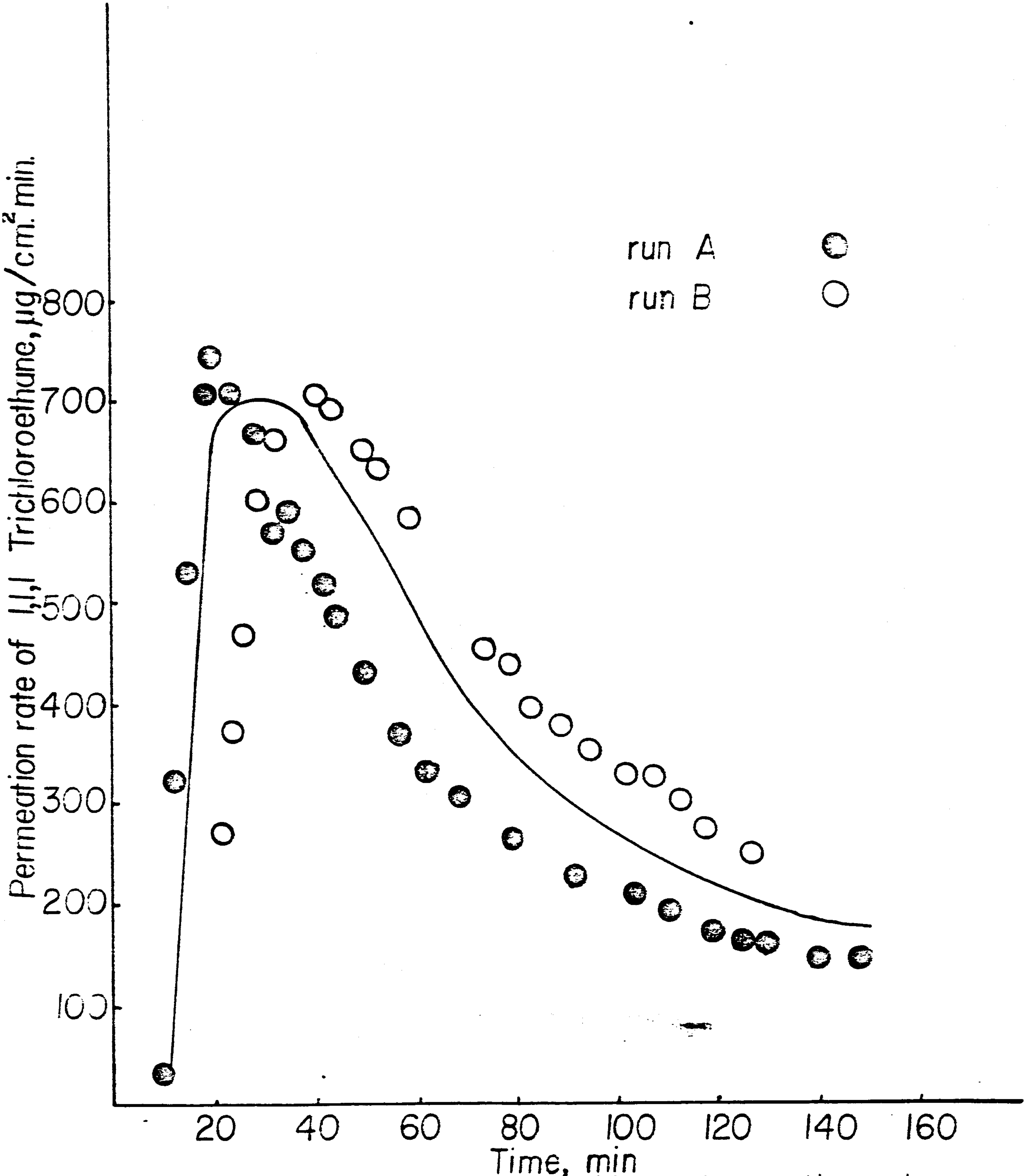

Fig. 11 Permeation of 1,1,1 Trichloroethane through Pioneer Pylox at room temperature Two-inch cell

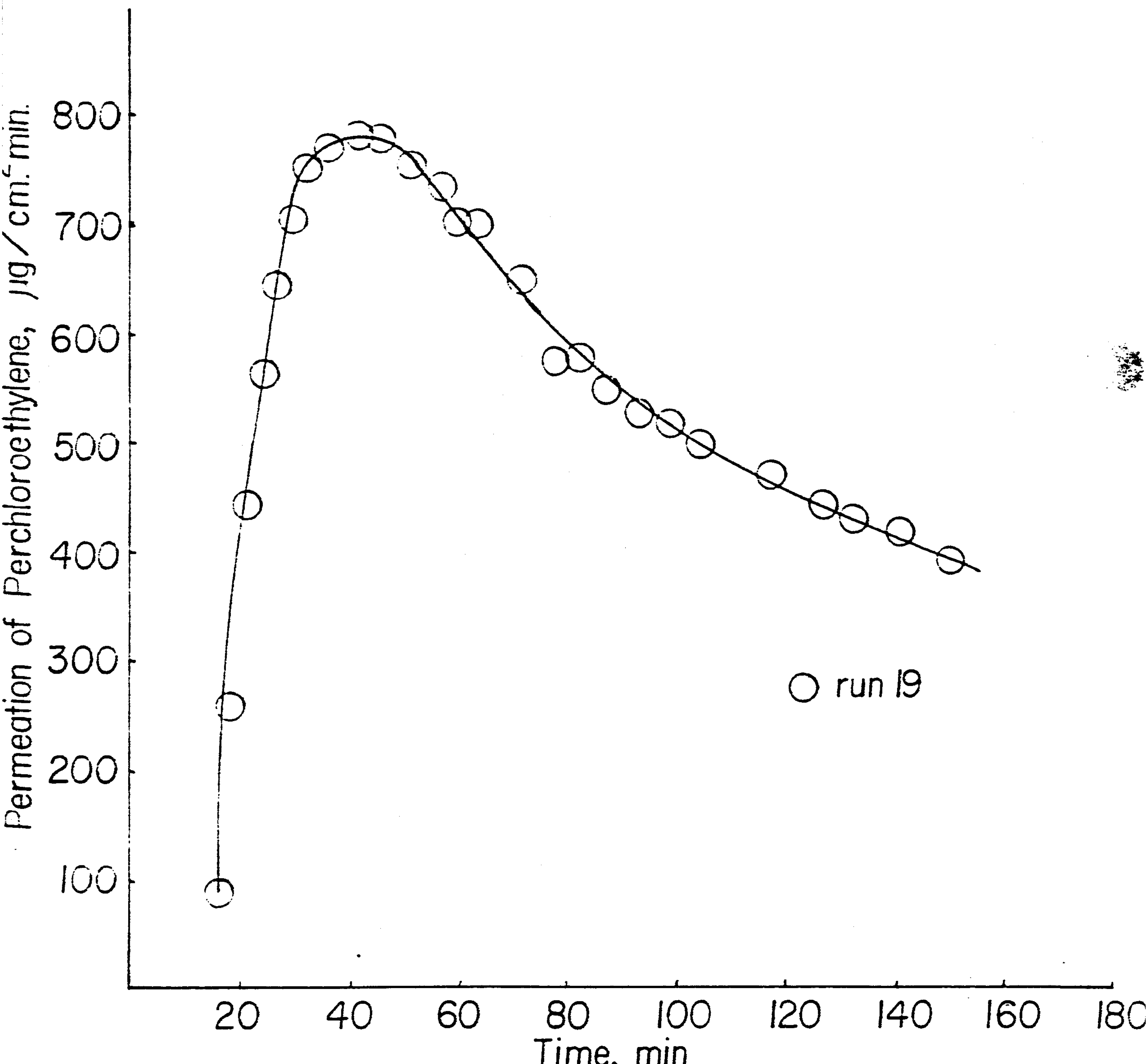

Fig. 12 Permeation of Perchloroethylene through Pioneer Pylox at room temperature, Two-inch cell

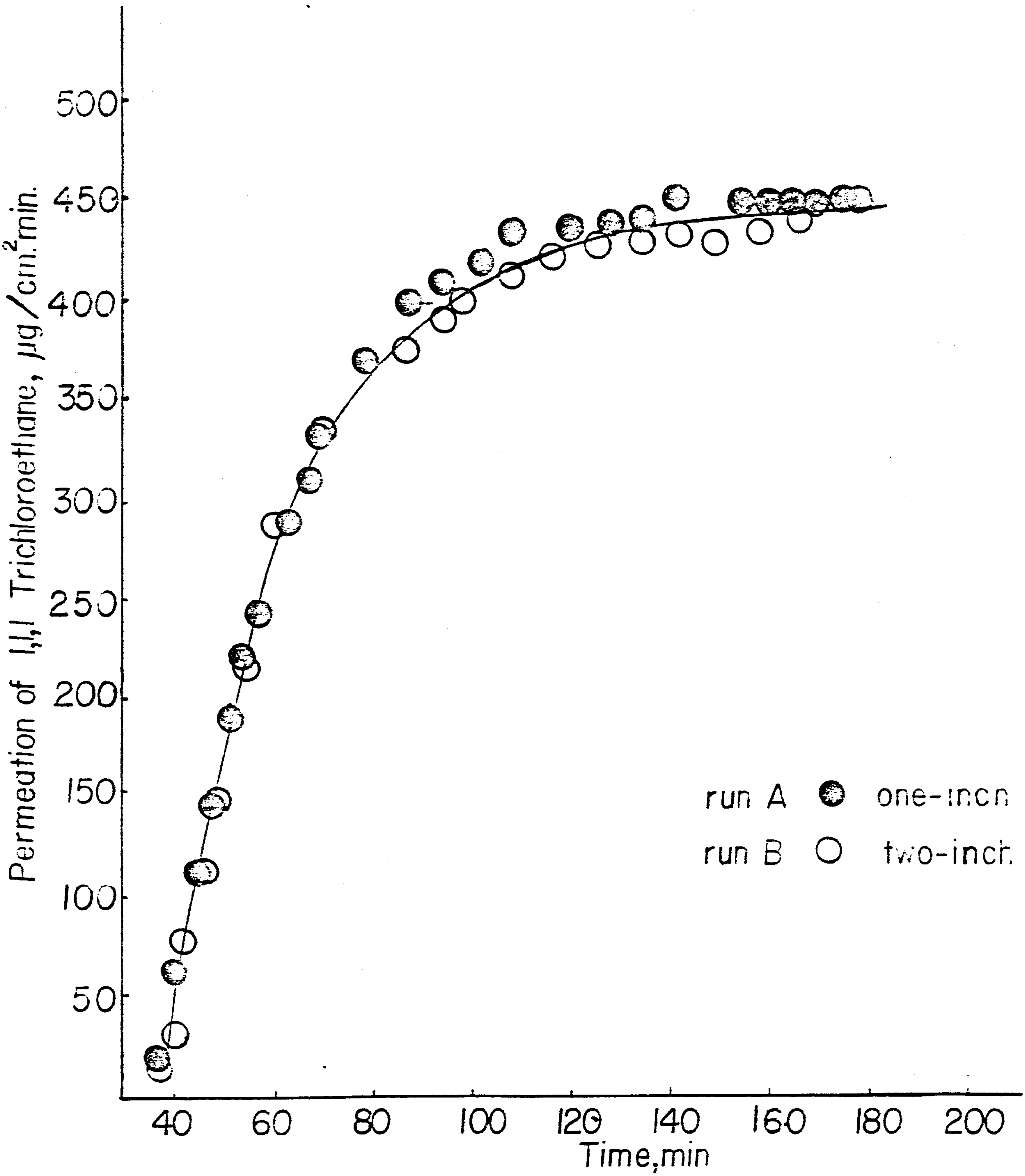

Fig. 13 Permeation rate of 1,1,1 Trichloroethane through Ansell NBR at room temperature

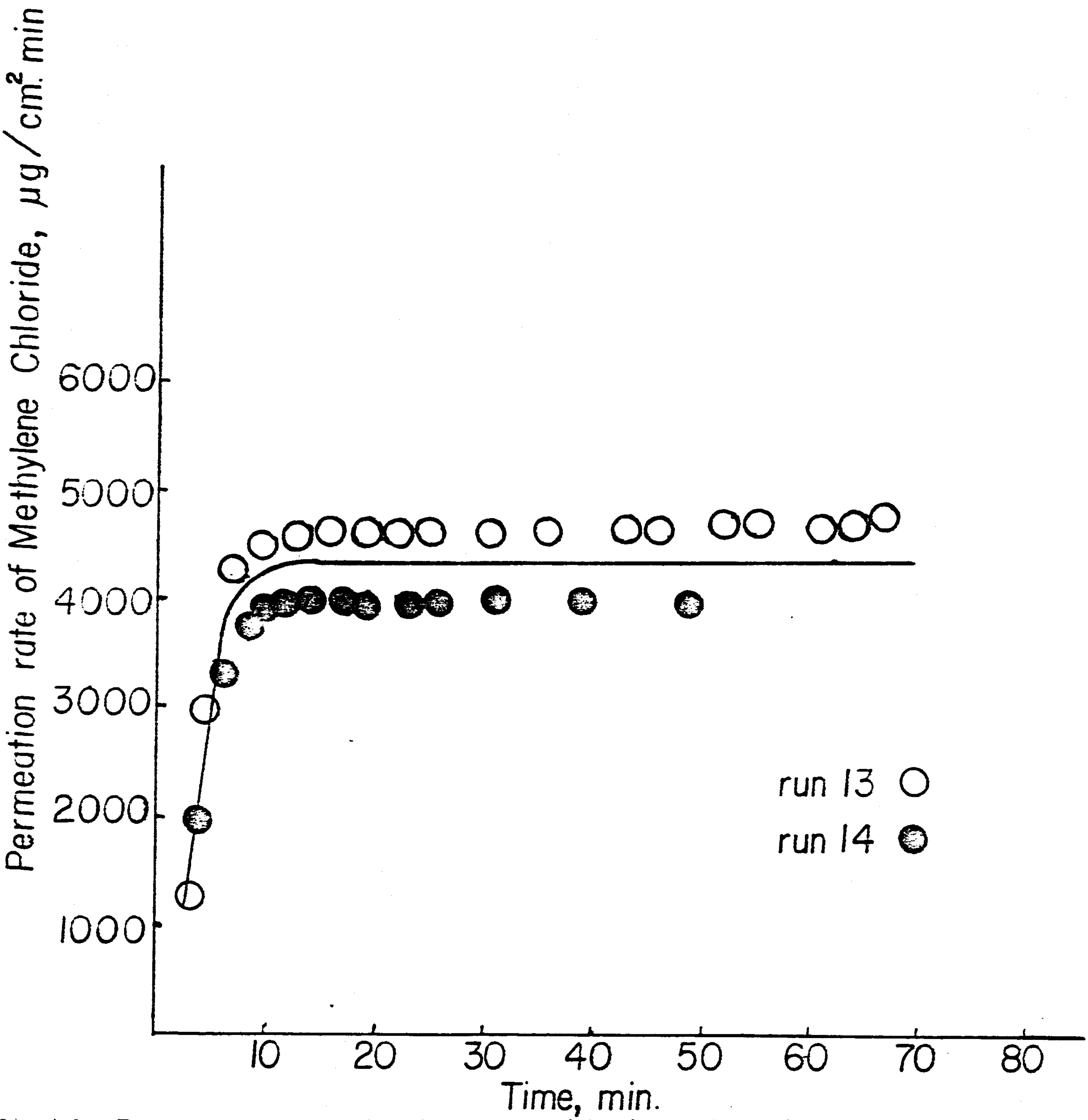

Fig.14 Permeation of Methylene Chloride-Ansell NBR Solvex
Two-inch cell, Room temperature

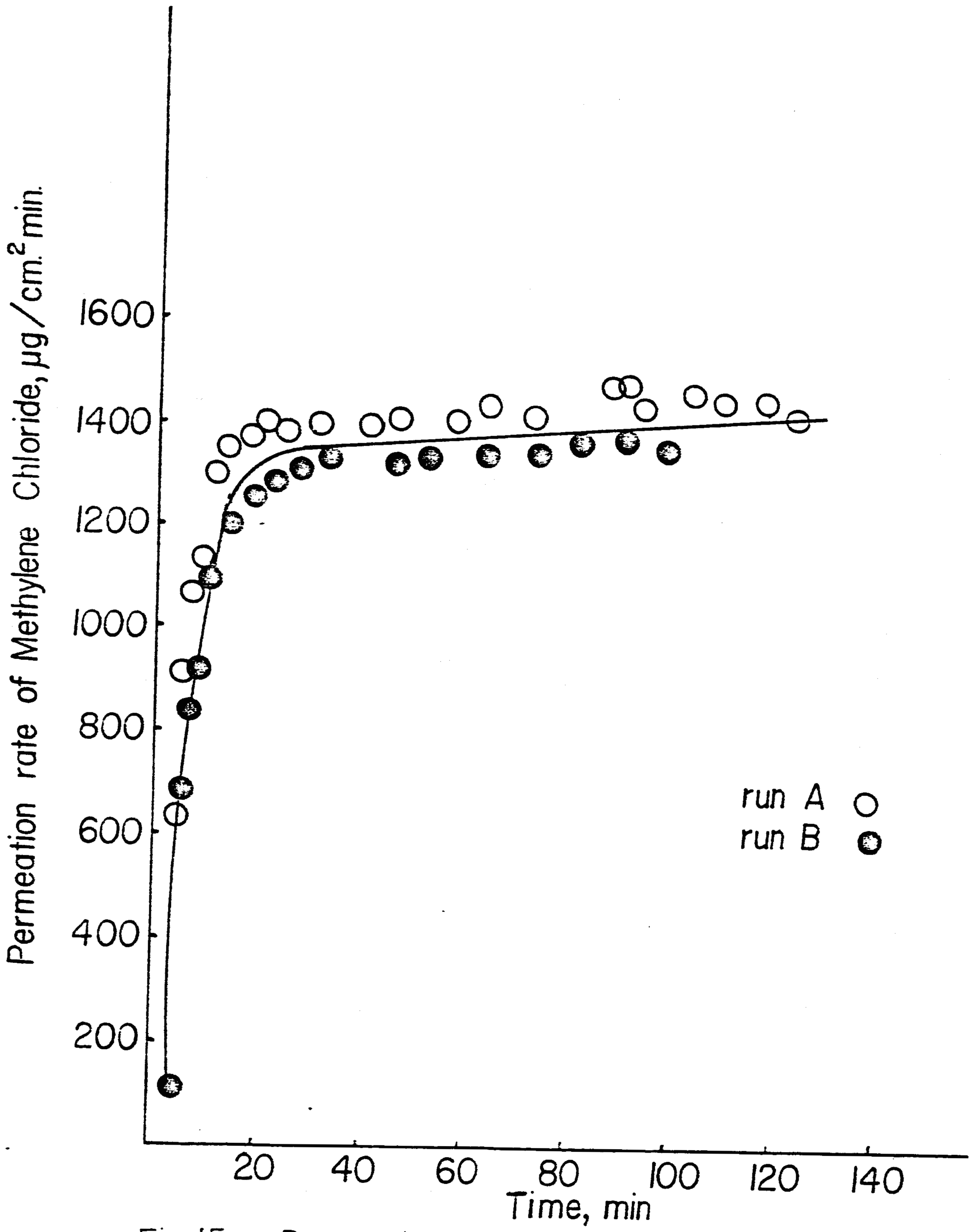

Fig. 15 Permeation of Methylene Chloride through Best NBR at room temperature
One-inch cell

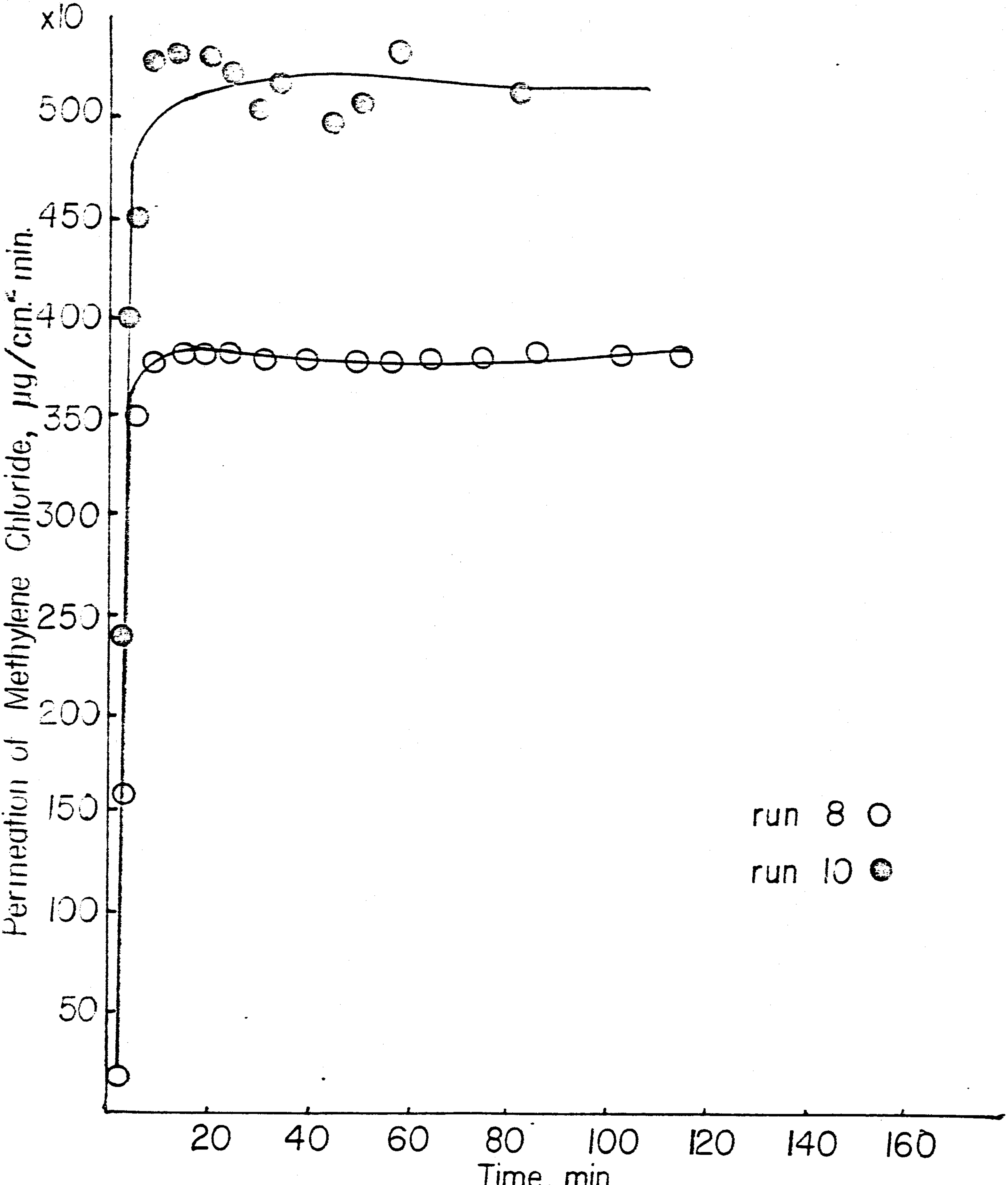

Fig. 16 Permeation of Methylene Chloride through Best NBR at room temperature Two-inch cell

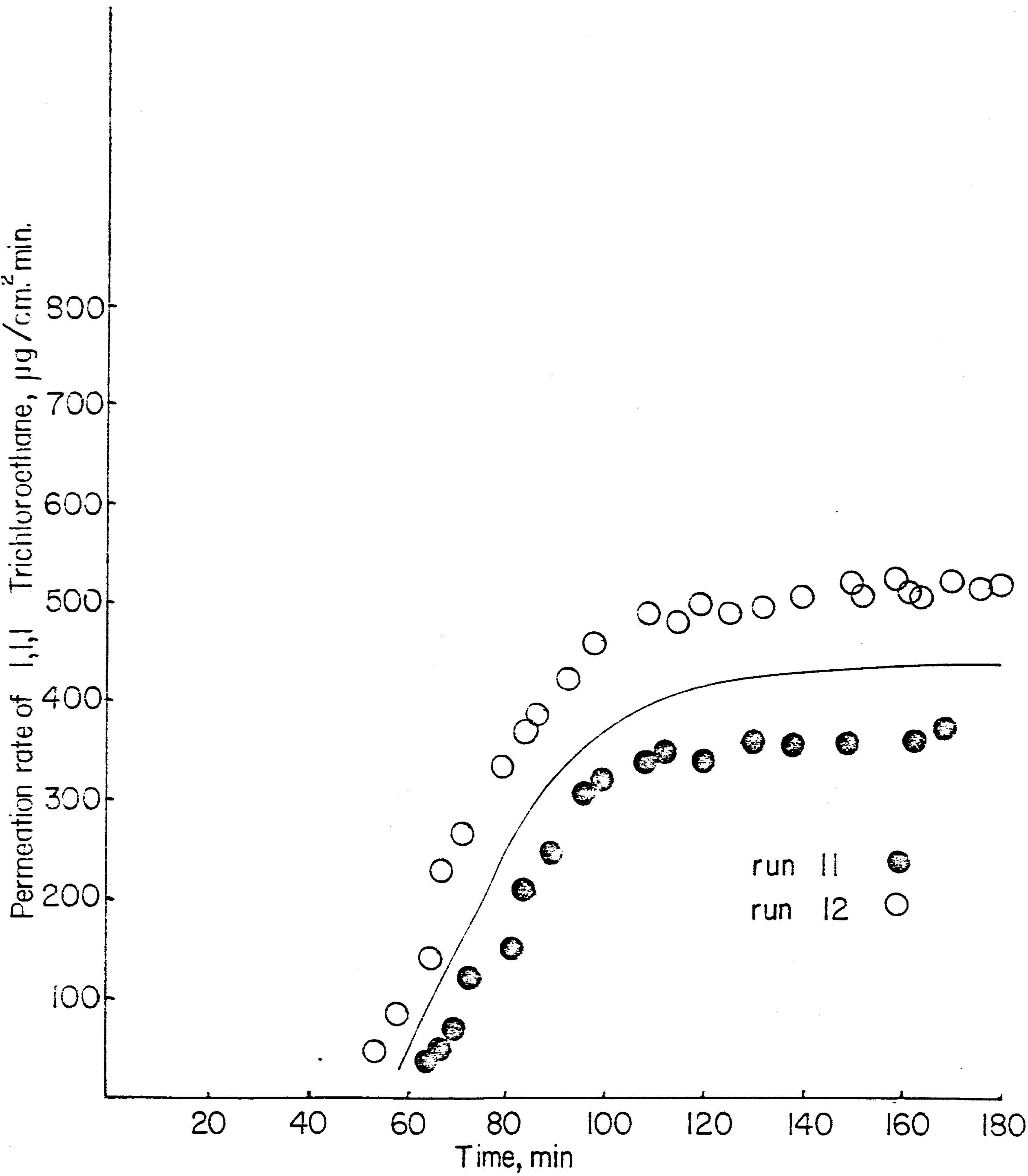

Fig. 17 Permeation of 1,1,1 Trichloroethane through Best NBR Solvex at room temperature. One-inch cell.

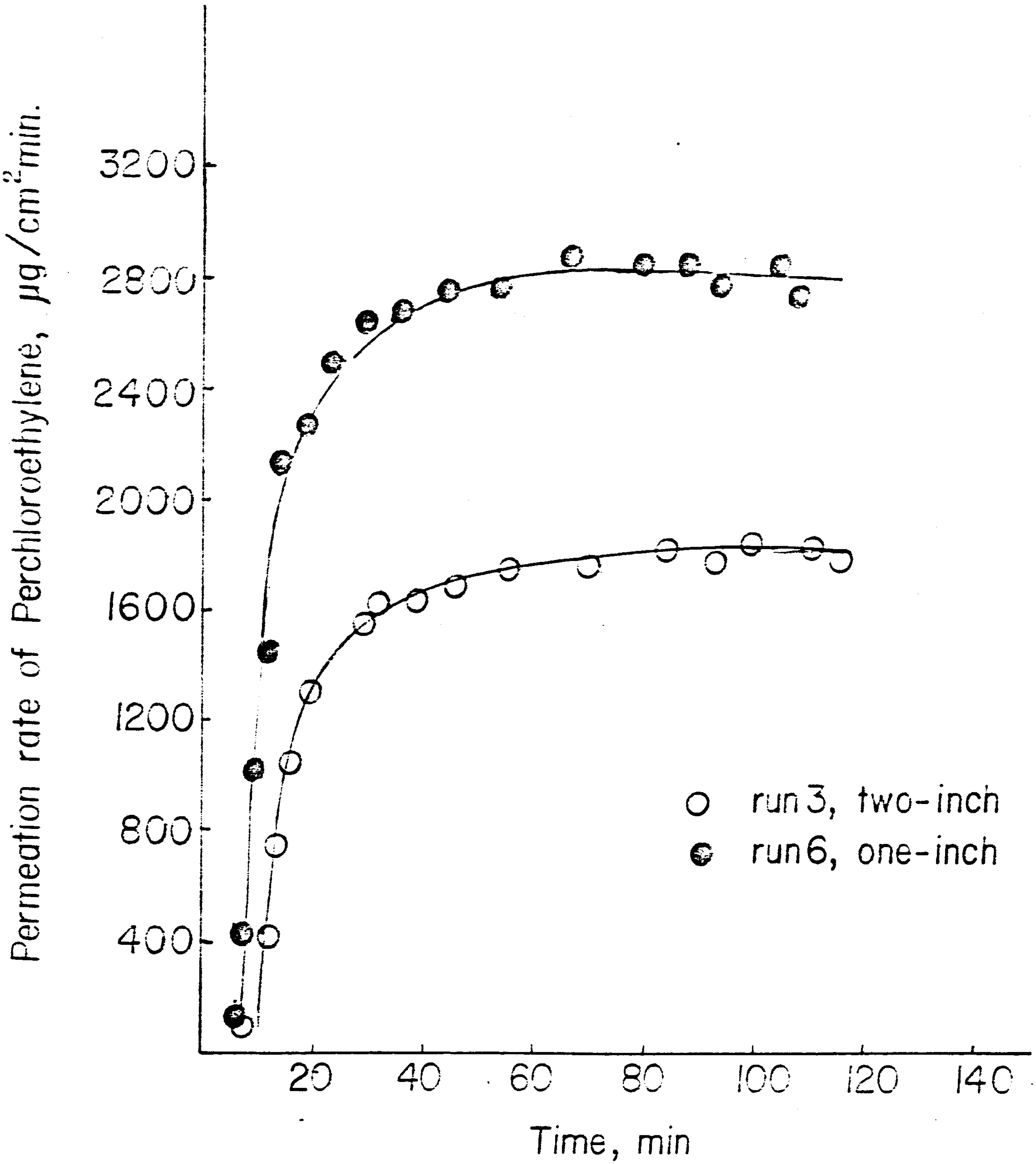

Fig 18 Permeation of Perchloroethylene through Ansell Neoprene at room temperature

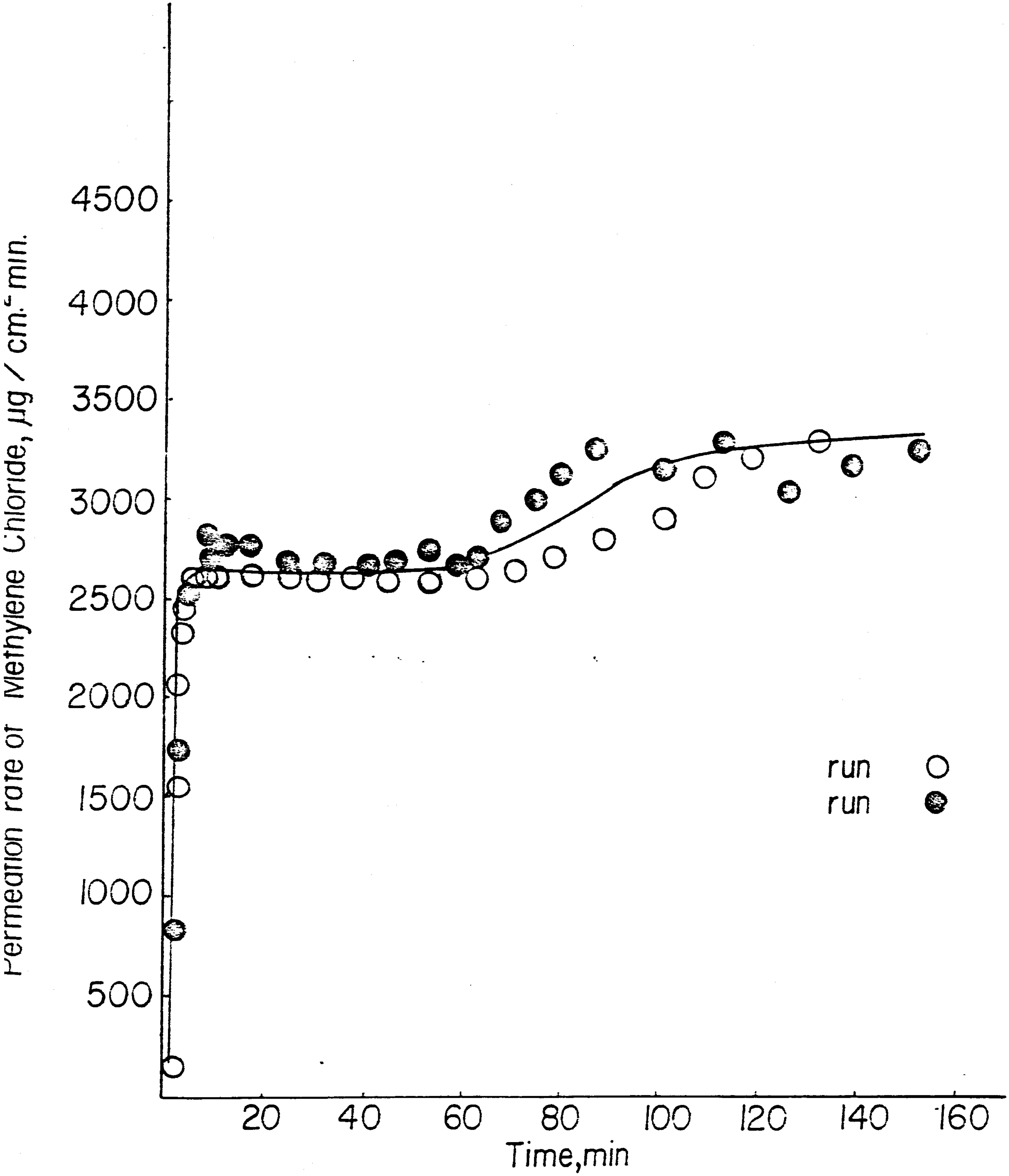

Fig. 19 Permeation of Methylene Chloride through Ansell Neoprene at room temperature
Two-inch cell

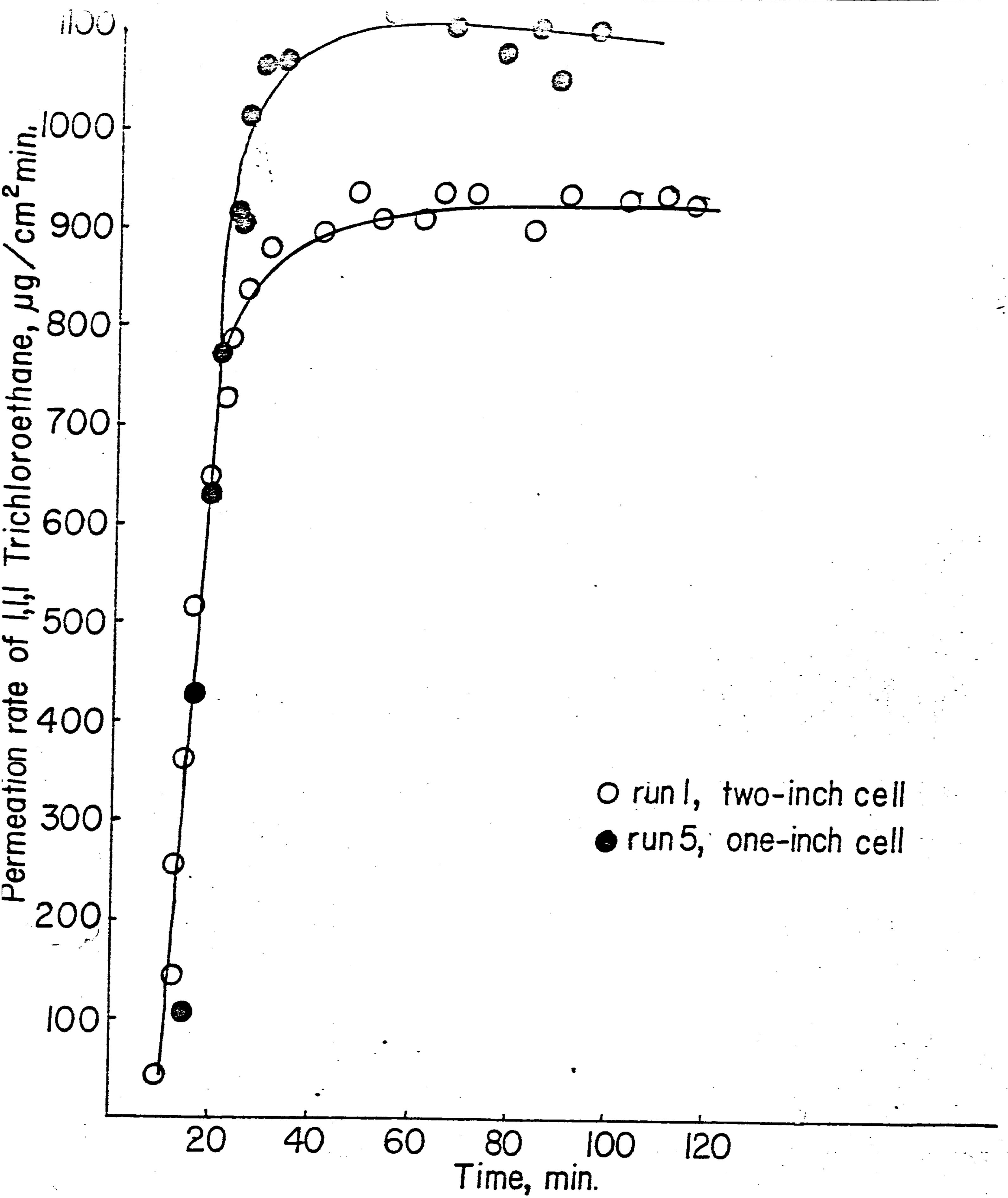

Fig. 20 Permeation of 1,1,1 Trichlorothane through Ansell Neoprene at room temperature

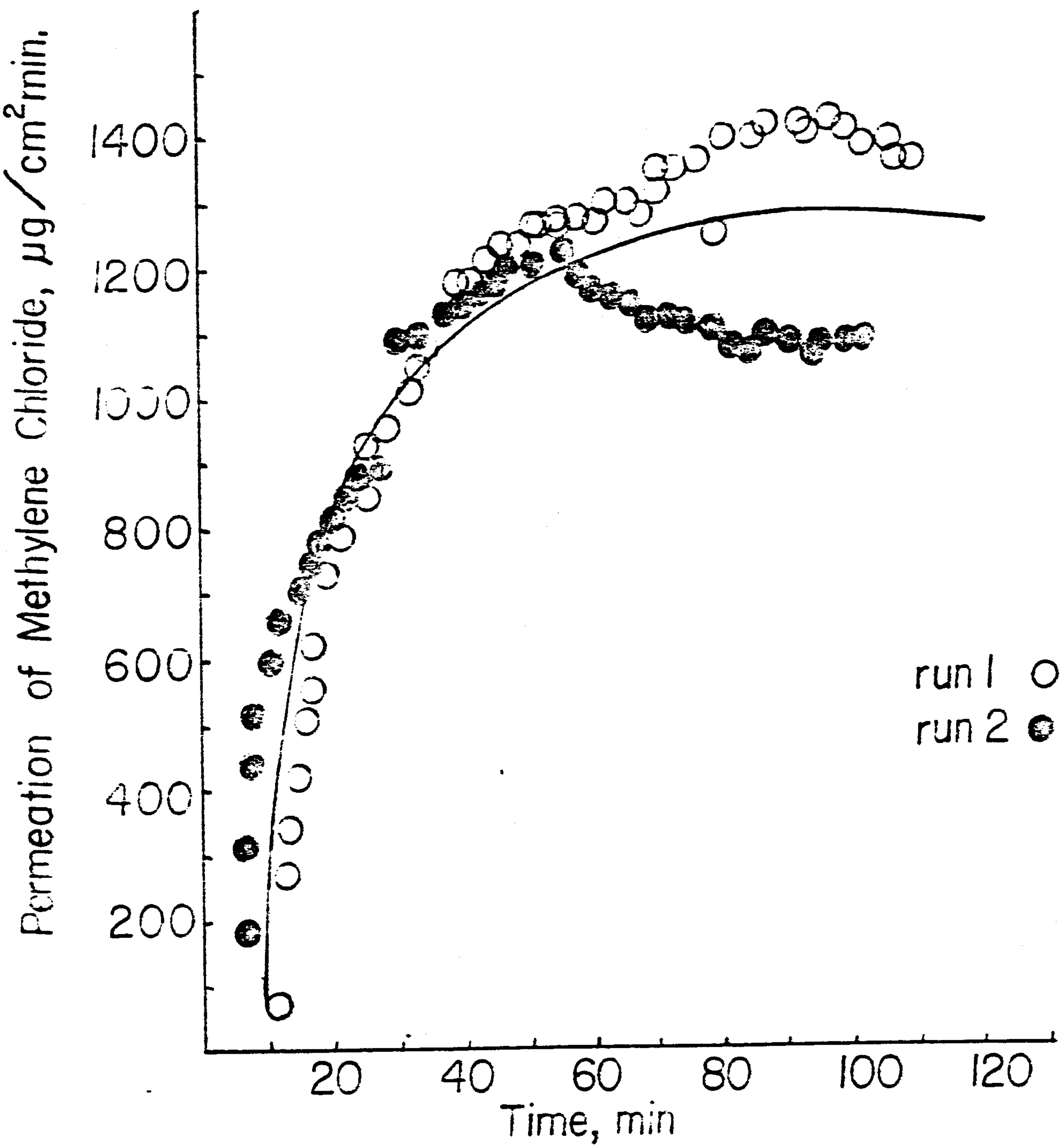

Fig. 21 Permeation of Methylene Chloride through Edmont 3-318 PVC at room temperature Two-inch cell

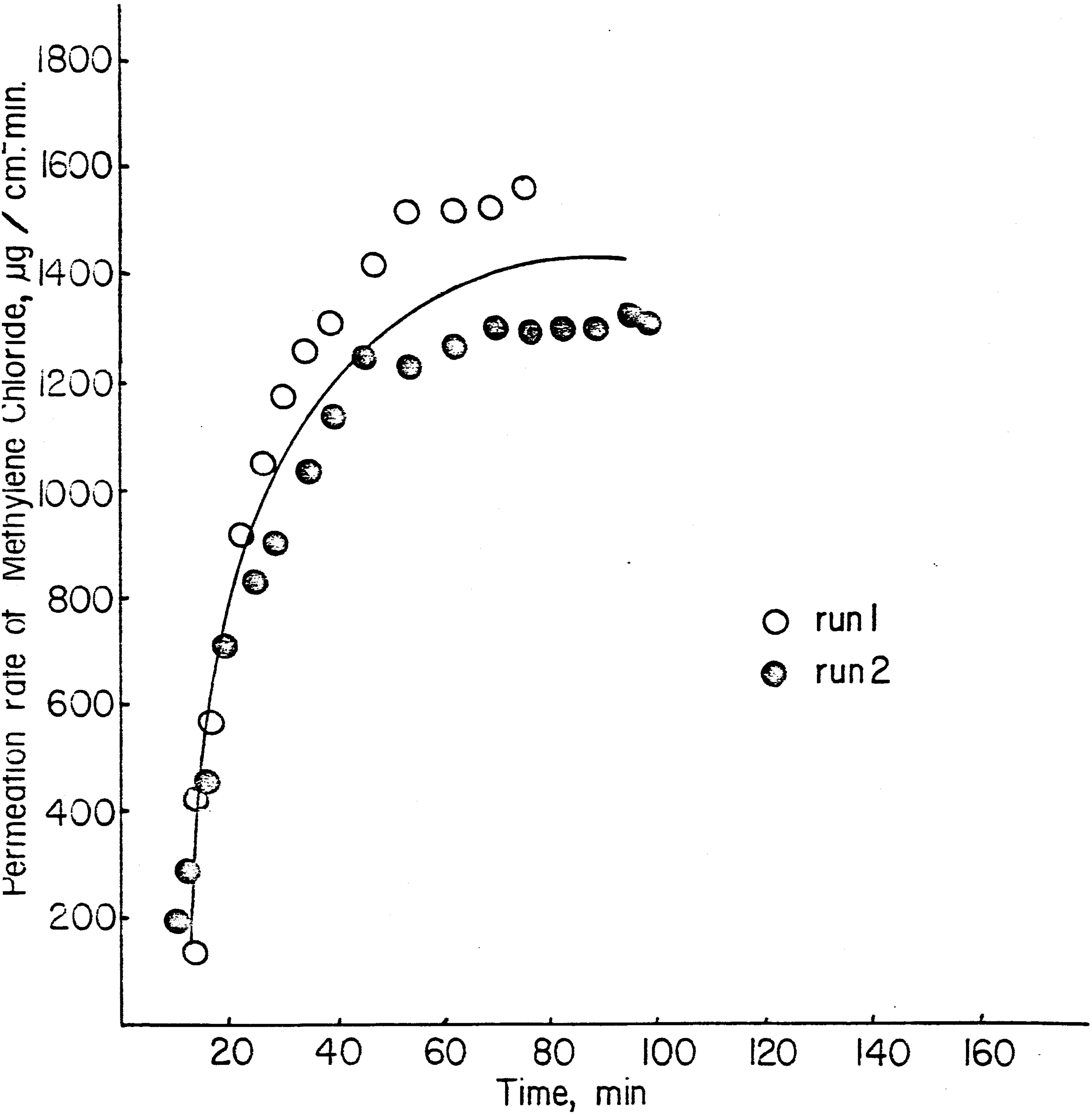

Fig. 22 Permeation of Methylene Chloride through Edmont 3-318 PVC at room temperature. one-inch cell

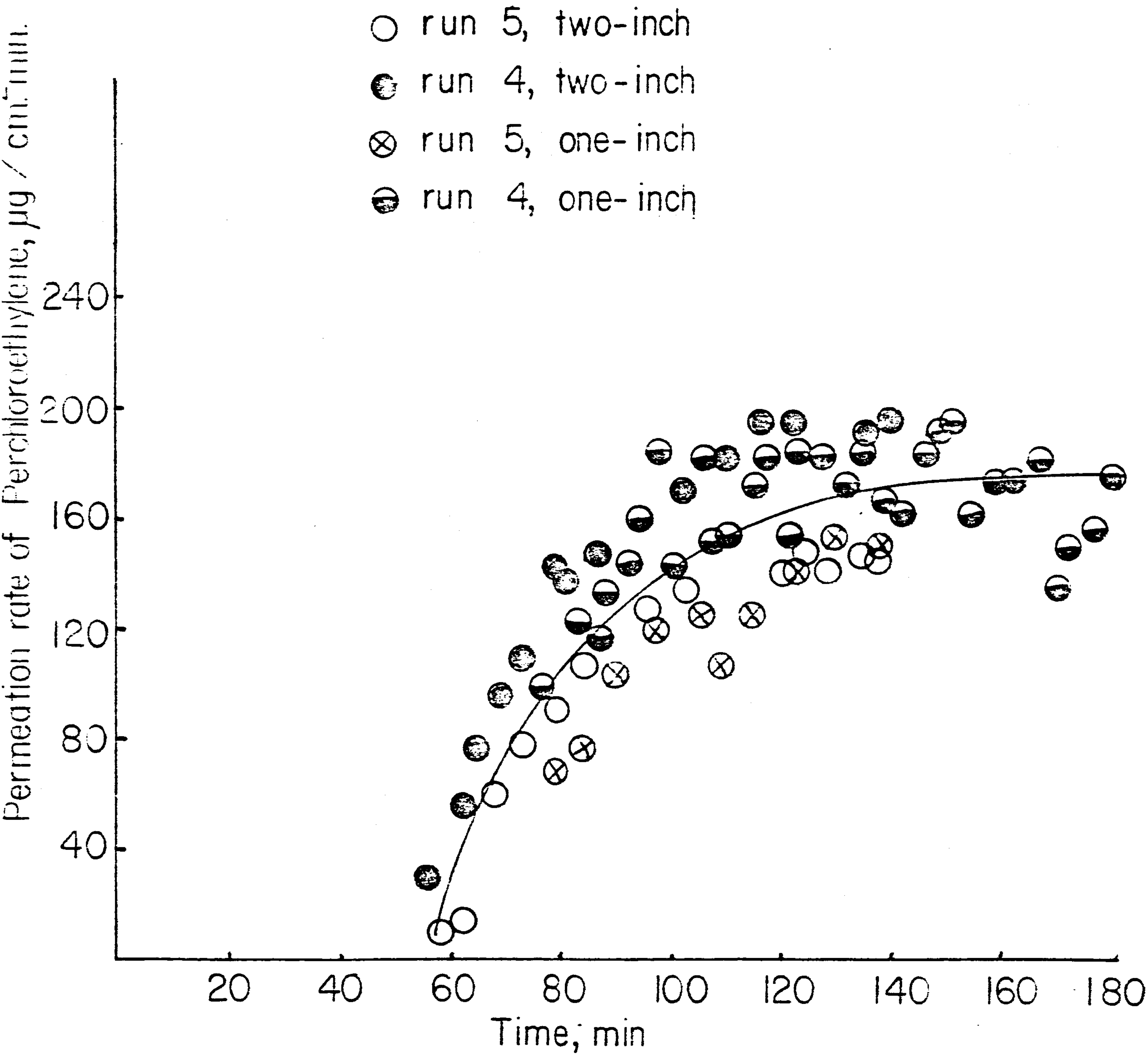

Fig.23 Permeation of Perchloroethylene through Edmont 3-318 PVC at room temperature.

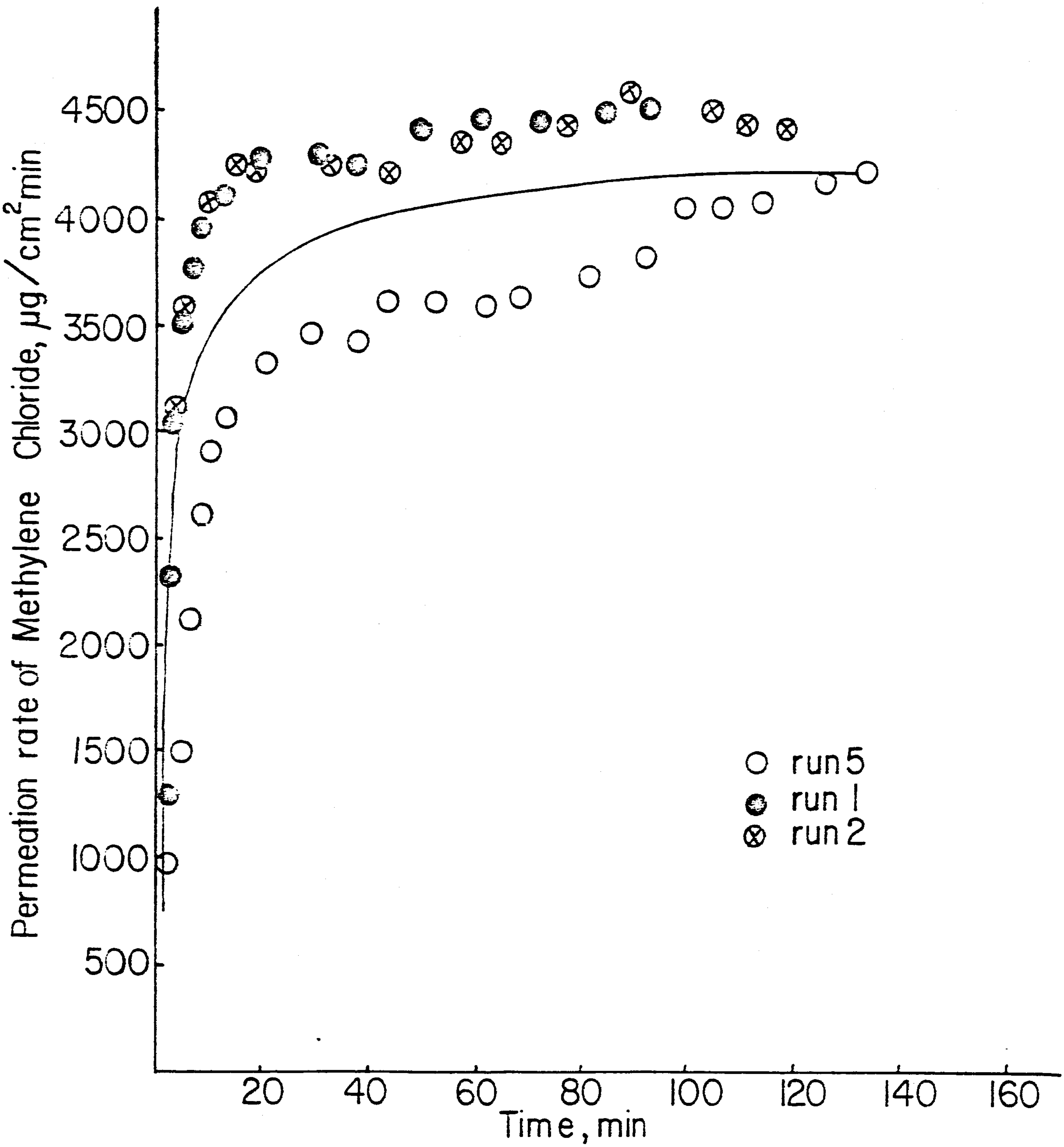

Fig. 24 Permeation of Methylene Chloride through Pioneer E-194 Combination. One-inch cell

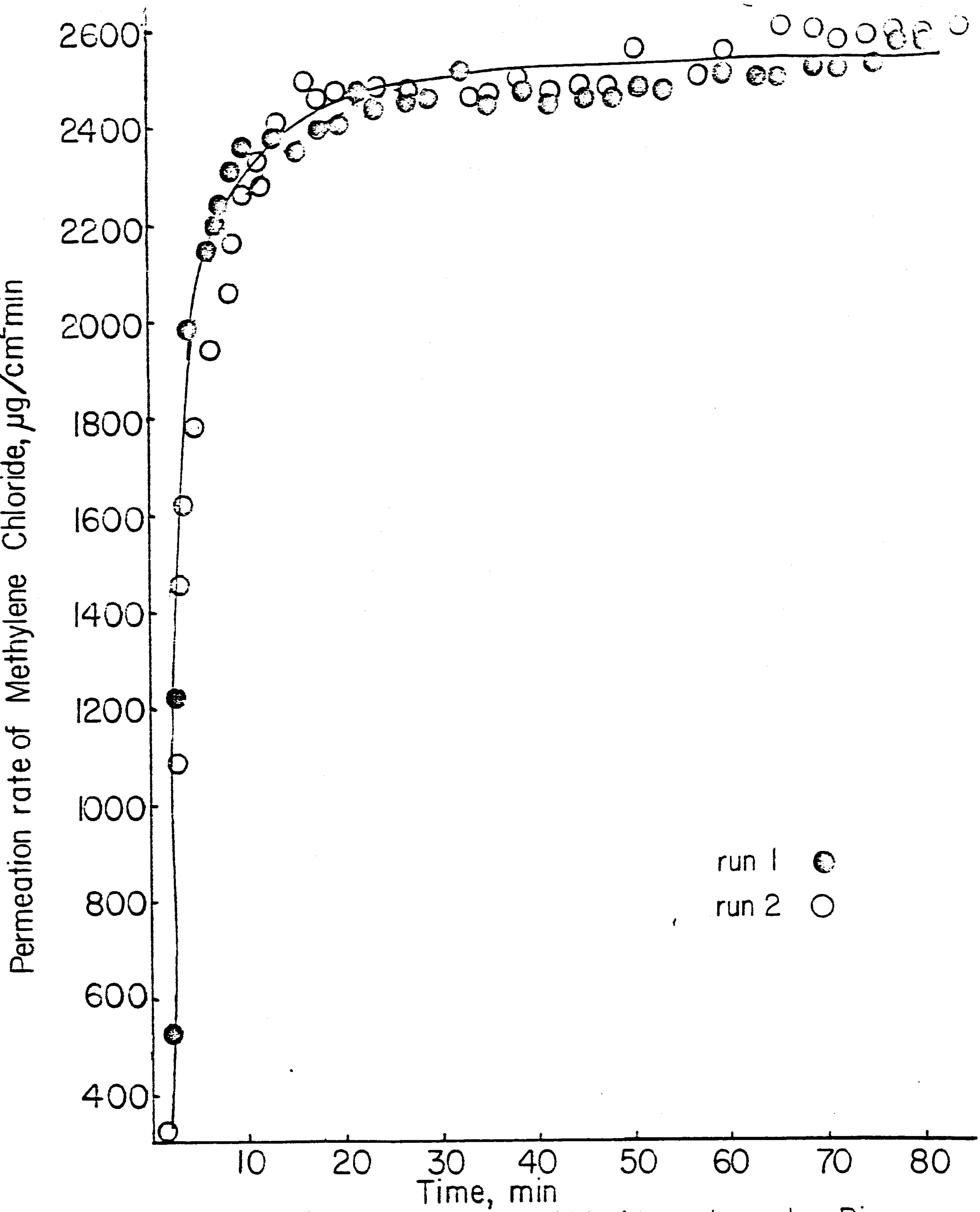

Fig.25 Permeation of Methylene Chloride through Pioneer E-194 Combination at room temperature. Two-inch cell

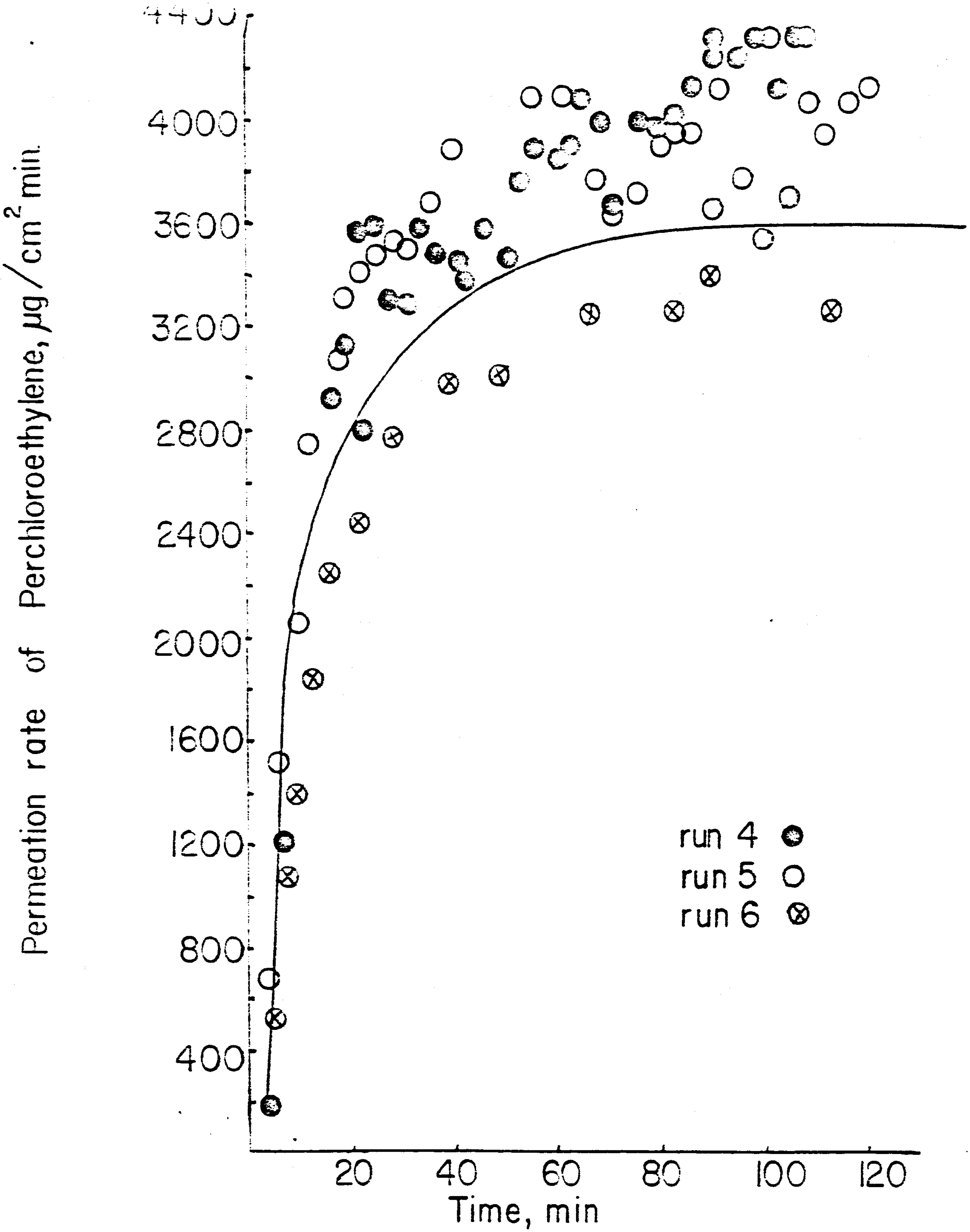

Fig. 26 Permeation of Permeation Perchloroethylene through Pioneer E-194 Combination, at room temperature. One-inch cell

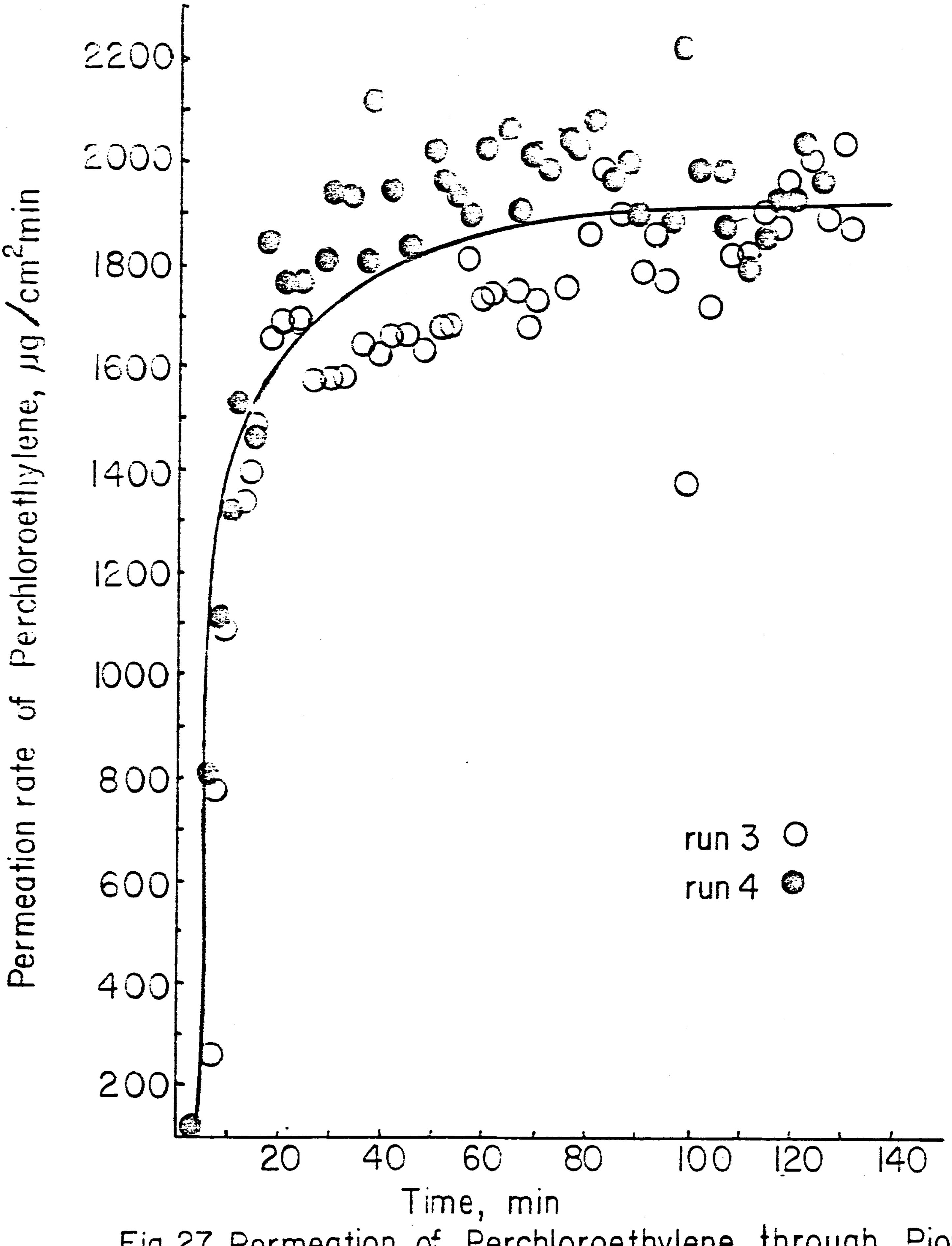

Fig.27 Permeation of Perchloroethylene through Pioneer E-194 Combination at room temperature Two-inch cell

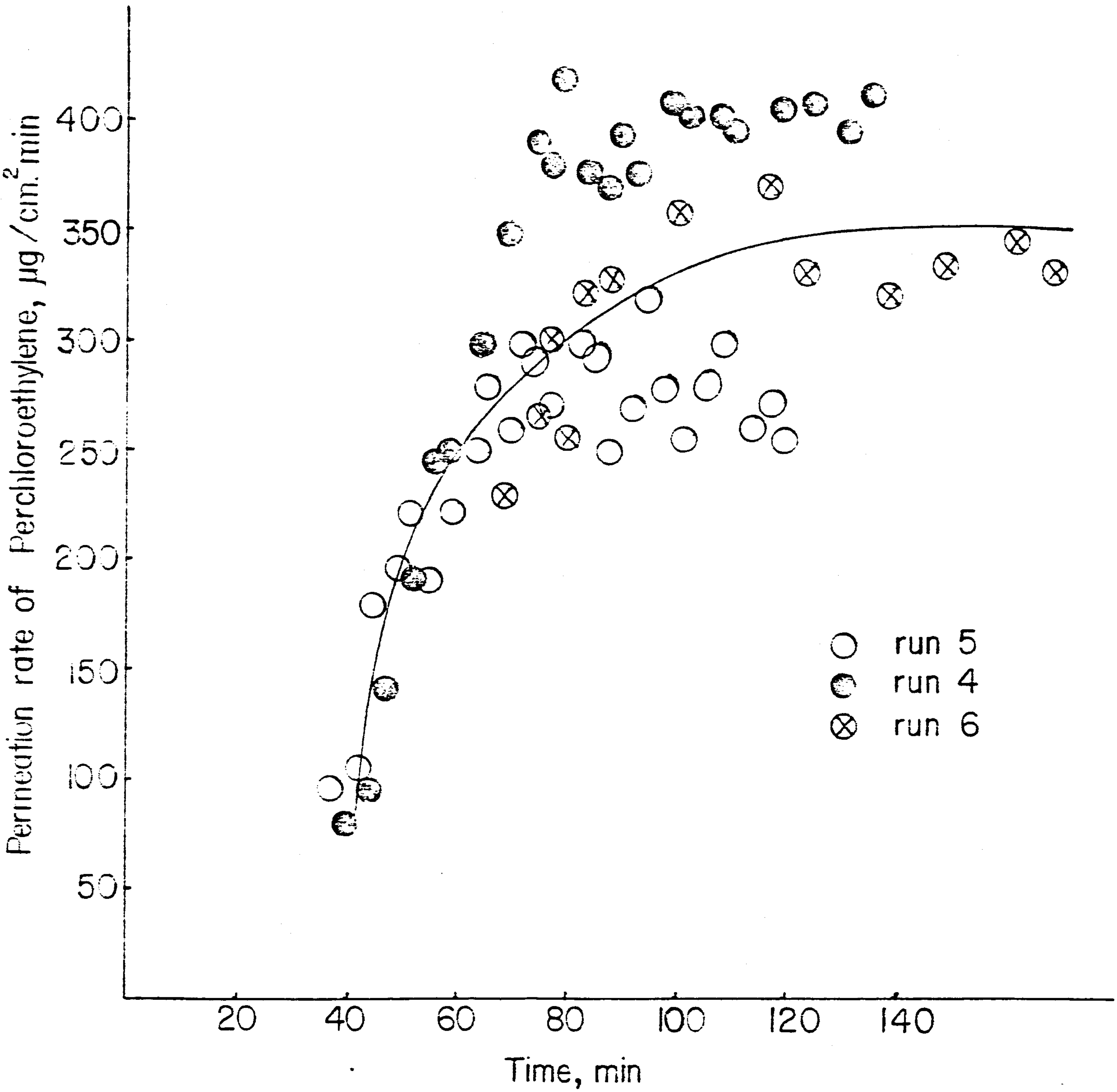

Fig. 28 Permeation of Perchloroethylene through Best 814 PVC, at room temperature. One-inch cell

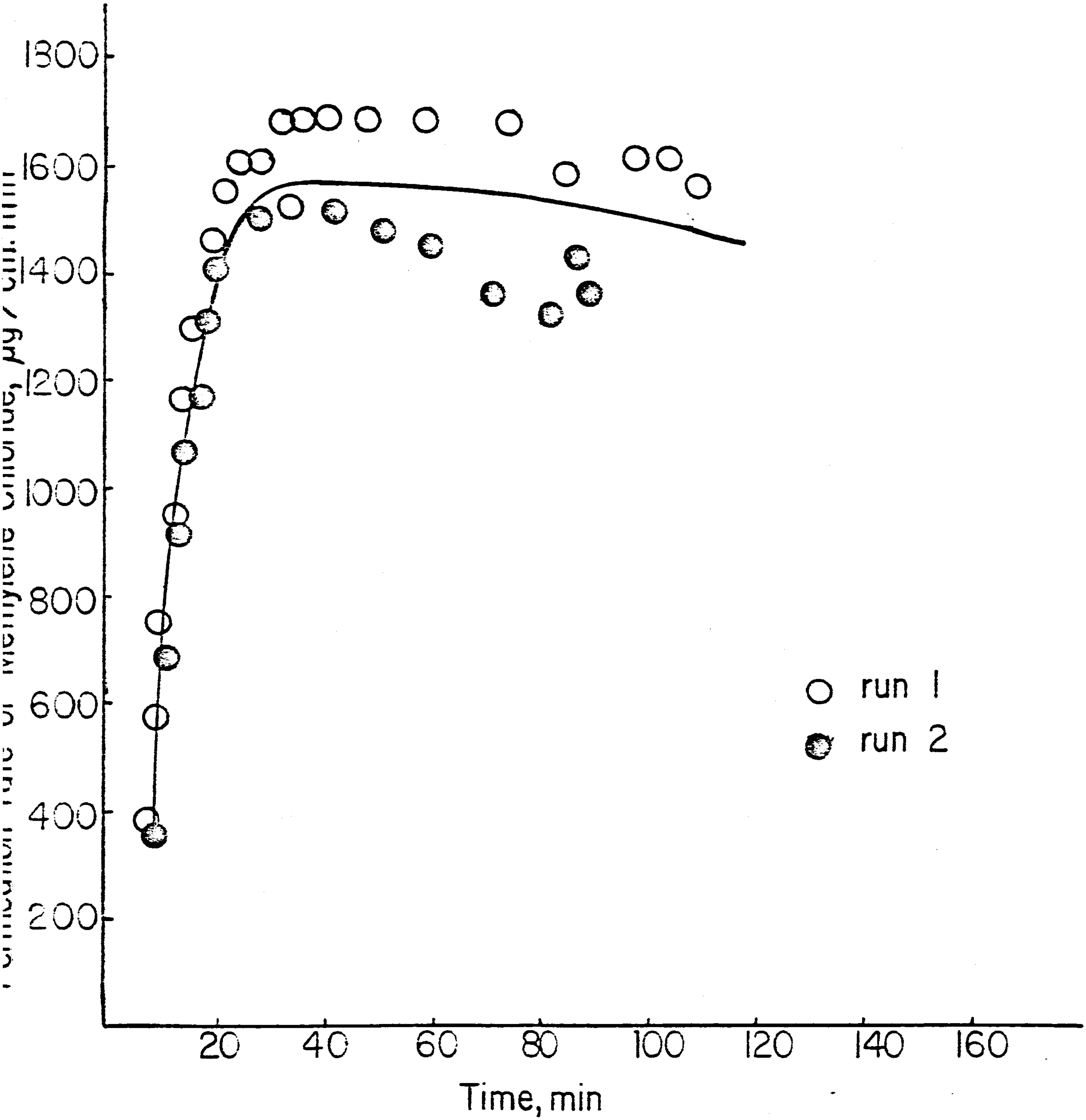

Fig.29 Permeation of Methylene Chloride through Best 814 PVC at room temperature. One-inch cell

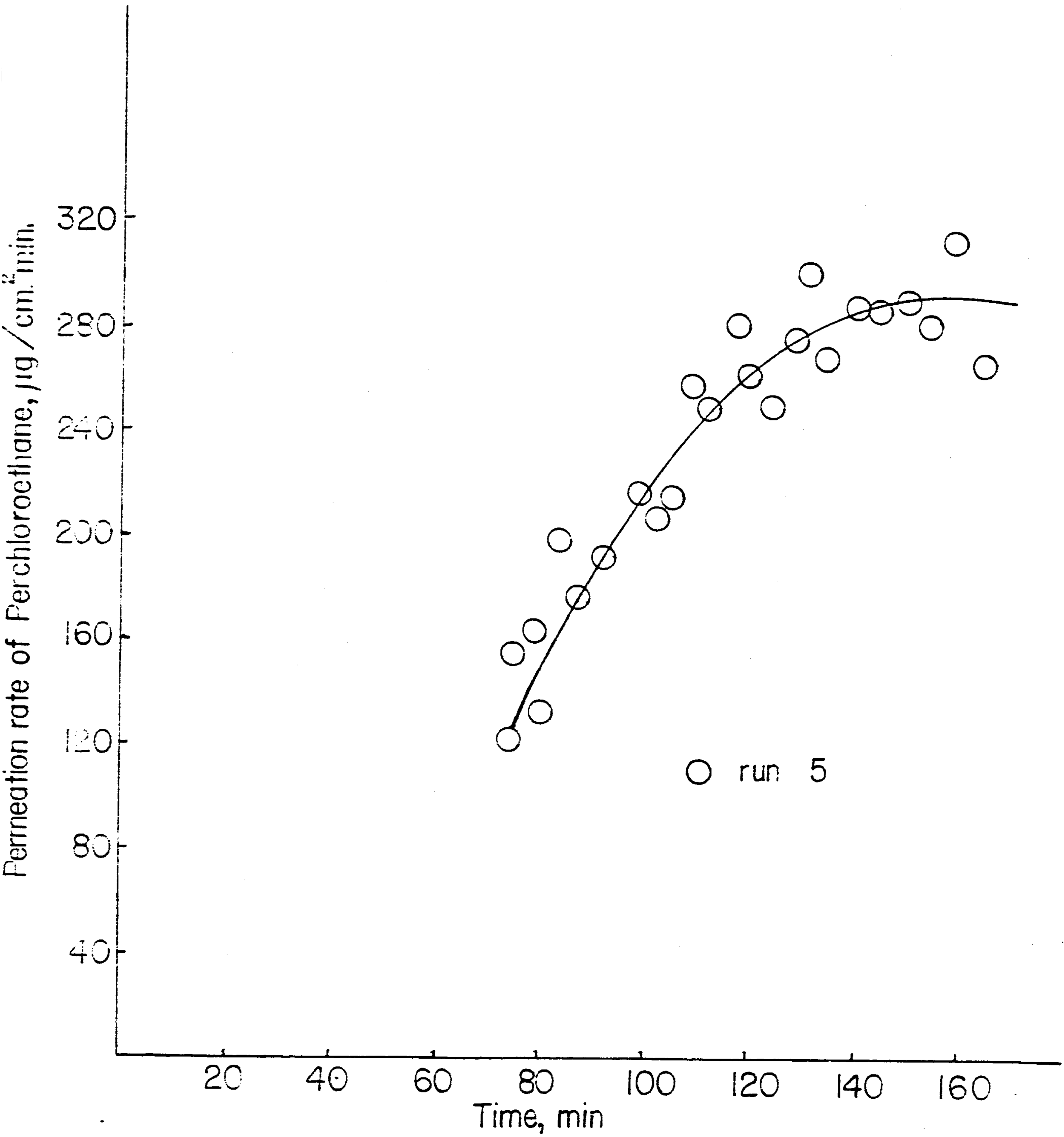

Fig. 30 Permeation rate of Perchloroethylene through Best 501 PVC at room temperature, One-inch cell

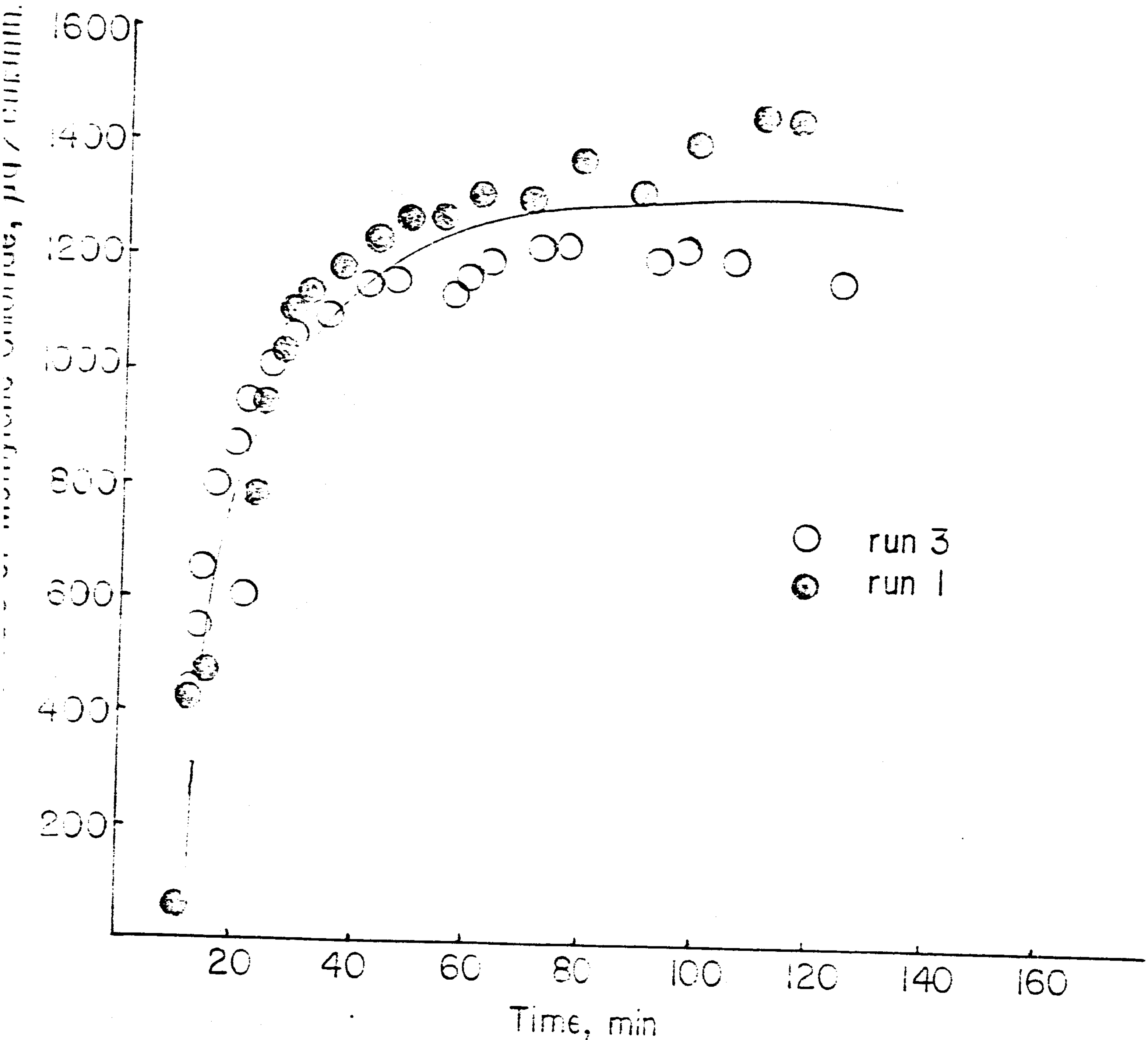

Fig. 3i Permeation of Methylene Chloride through Best 501 PVC at room temperature. One-inch cell